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**UTILITY
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TADAHIRO OHMI, ET AL.

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APPLICATION ELEMENTS

See MPEP chapter 600 concerning utility patent application contents.

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Box Patent Application
Washington, DC 202311. ☒ Fee Transmittal Form
(Submit an original, and a duplicate for fee processing)2. ☒ Specification Total Pages **128**3. ☒ Drawing(s) (35 USC 113) Total Sheets **57**4. ☒ Oath or Declaration Total Pages **2**

- a. ☐ Newly executed (original or copy)
b. ☒ Unexecuted for information purposes
c. ☐ Copy from a prior application (37 CFR 1.63(d))
(for continuation/divisional with Box 17 completed)
[Note Box 5 below]

☐ **DELETION OF INVENTOR(S)**Signed Statement attached deleting inventor(s)
named in the prior application, see 37 CFR
1.63(d)(2) and 1.33(b).5. ☐ Incorporation By Reference (useable if Box 4c is checked)
The entire disclosure of the prior application, from which a copy of the
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ACCOMPANYING APPLICATION PARTS

8. ☐ Assignment Papers (cover sheet & document(s))
9. ☐ 37 CFR 3.73(b) Statement ☐ Power of Attorney
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17. If a CONTINUING APPLICATION, check appropriate box and supply the requisite information:

☐ Continuation ☐ Divisional ☐ Continuation-in-part (CIP) of prior application No.**18. CORRESPONDENCE ADDRESS**☒ Customer Number or Bar Code Label**05514**

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CLAIMS	(1) FOR	(2) NUMBER FILED	(3) NUMBER EXTRA	(4) RATE	(5) CALCULATIONS
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19. Small entity status

- a. ☐ A Small entity statement is enclosed
- b. ☐ A small entity statement was filed in the prior nonprovisional application and such status is still proper and desired.
- c. ☐ Is no longer claimed.

20. ☒ A check in the amount of \$ 2,274.00 to cover the filing fee is enclosed.

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- a. ☒ Fees required under 37 CFR 1.16.
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- c. ☐ Fees required under 37 CFR 1.18.

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT REQUIRED

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DATE	February 1, 2000

TITLE OF THE INVENTION
LASER OSCILLATING APPARATUS, EXPOSURE APPARATUS
USING THE SAME, AND DEVICE FABRICATION METHOD

5 BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

The present invention relates to a laser oscillating
apparatus for generating a laser beam by introducing an
10 electromagnetic wave from a waveguide into a laser tube
through a plurality of fine gaps formed in the waveguide wall
and, more specifically, to a laser oscillating apparatus
using a microwave as an electromagnetic wave for exciting
a laser gas, an exposure apparatus using the same, and a device
15 fabrication method.

DESCRIPTION OF THE RELATED ART

Recently, a so-called excimer laser has attracted
attention as the only high-output laser which oscillates in
20 the ultraviolet region. This excimer laser is expected to
be applied to the electronic, chemical, and energy industries,
particularly processing and chemical reactions of metals,
resins, glass, ceramics, and semiconductors.

The principle of function of an excimer laser
25 oscillator will be described below. First, laser gases such
as Ar, Kr, Ne, F₂, He, Xe, and Cl₂ contained in a laser tube

fine gaps (slots) 9202 are formed at equal intervals in a waveguide wall 9201. For convenience, the interior of a laser tube is schematically shown as an emission space.

When this slot array structure is used, regions
5 (hatched elliptic regions in Fig. 55) between adjacent slots 9202 are necessarily microwave non-irradiation regions. Accordingly, when a laser gas existing in the emission space is to be excited by a microwave, the existence of these non-irradiation regions produces variations in the microwave
10 intensity. This generates plasma discharge having a nonuniform distribution as a whole.

As described above, it is difficult to uniformize the radiation characteristic of an electromagnetic wave from a slot formed in a waveguide wall in an entire region over the
15 slot. Usually, the distribution is a sinusoidal distribution in the slot long-axis direction or a similar distribution. That is, as shown in Fig. 56A, an electric field intensity distribution in the center along the slot long-axis direction is largest, and the field intensity
20 distribution at the ends in the slot long-axis direction is smallest.

Additionally, as shown in Fig. 56B, an excited plasma has a property of concentrating to the center in the slot long-axis direction with respect to the microwave field
25 intensity distribution. This promotes the nonuniform distribution of the field intensity in the slot long-axis

direction. This is a great cause of preventing a uniform distribution of a plasma excited in the slot longitudinal direction.

5 This phenomenon is caused by the property that a plasma is easily excited in a central position along the slot longitudinal direction because the intensity of an electromagnetic wave as an excitation source is a maximum in this central position, and by the property that the excited plasma readily concentrates into the form of a sphere having
10 the smallest surface area. This plasma excited in the central position forms a region having a low spatial impedance in the center of the slot. This portion preferentially consumes energy. Also, the plasma functions as a shield to reduce the slot length, which is designed to
15 be the one by which a microwaves is emitted, to half that required by a microwave. This makes it difficult to emit a microwave outside the slot. By these two factors, a plasma is readily formed only in the center of a slot, and it is very difficult to excite a uniform plasma over the slot.

20 Furthermore, a plasma is generated immediately close to the microwave emission surface over a slot. However, in a plasma sheath formed over the slot a microwave can propagate. As a consequence, a microwave extends in the slot short-axis direction via this sheath region and disperses the input
25 power. This makes it impossible to satisfy energy density necessary to excite an excimer laser. The reason for this

is that when a plasma is diffused in a wide space, energy used to generate the plasma disperses, and this makes it difficult to realize enough energy density to excite an excimer.

5 Fig. 57 is a schematic view showing the way a microwave propagates via a plasma sheath. That is, Fig. 57 is a sectional view taken along a direction perpendicular to the longitudinal direction of a slot.

10 Although a plasma is not electrically grounded over the slot, the outside of the plasma is basically grounded directly to a waveguide 1. This results in a sheath potential difference and a sheath width difference between them. Therefore, if the plasma density is insufficient, the thickness of the sheath increases, and this results in easy
15 nonuniform outward leakage of a microwave. Consequently, the plasma is thin immediately above the open end of the slot and thick on the outside.

SUMMARY OF THE INVENTION

20 The present invention has been made in consideration of the above situation, and has as its object to provide a laser oscillating apparatus which uses a slot array structure and yet realizes electromagnetic wave radiation uniform as a whole over the length of a laser tube and allows uniform
25 laser emission with minimum energy loss, a high-performance exposure apparatus including this laser oscillating

apparatus, and a high-quality device fabrication method using this exposure apparatus.

It is another object of the present invention to provide a laser oscillating apparatus which uses a slot array structure and yet suppresses diffusion of a plasma generated over a slot and allows uniform laser emission with minimum energy loss, a high-performance exposure apparatus including this laser oscillating apparatus, and a high-quality device fabrication method using this exposure apparatus.

10 A laser oscillating apparatus for achieving the above objects according to the present invention is a laser oscillating apparatus for exciting a laser gas in a laser tube by introducing an electromagnetic wave from a waveguide into the laser tube through a plurality of fine gaps formed in a waveguide wall, and generating a laser beam by resonating light emitted from the laser gas, wherein the fine gaps and a wall of the laser tube are spaced apart by a predetermined distance to form an electromagnetic wave passage.

20 According to one aspect of the laser oscillating apparatus of the present invention, the distance from the fine gaps to the laser tube wall is an integral multiple of the half-wave length of an electromagnetic wave introduced from the waveguide.

25 According to another aspect of the laser oscillating apparatus of the present invention, an electromagnetic wave introduced from the waveguide is a microwave.

According to still another aspect of the laser oscillating apparatus of the present invention, a conductor is so formed as to surround the passage including the fine gaps, and the passage is an air gap with a predetermined width.

5 According to still another aspect of the laser oscillating apparatus of the present invention, the air gap is filled with a dielectric member.

10 According to still another aspect of the laser oscillating apparatus of the present invention, the width of the air gap is an integral multiple of the half-wave length of an electromagnetic wave introduced from the waveguide.

15 According to still another aspect of the laser oscillating apparatus of the present invention, only a distal end portion of the air gap is narrowed, and the air gap has the shape of a slit over the length of the laser tube in a portion where the air gap is in contact with the laser tube.

20 According to still another aspect of the laser oscillating apparatus of the present invention, the air gap is widened only in the vicinity of a distal end portion, and the width is substantially equal to the wavelength or the half-wave length of an electromagnetic wave introduced from the waveguide.

25 According to still another aspect of the laser oscillating apparatus of the present invention, the width near the distal end portion of the air gap changes along a longitudinal direction of the air gap by reflecting an

intensity distribution of electromagnetic waves emitted from the fine gaps.

According to still another aspect of the laser oscillating apparatus of the present invention, dielectric
5 lenses each having a symmetrical shape with respect to the fine gap are formed in the passage in at least a portion above the plurality of fine gaps.

According to still another aspect of the laser oscillating apparatus of the present invention, the
10 waveguide is filled with a dielectric member.

In the laser oscillating apparatus described above, the fine gaps (slots) formed in the waveguide wall and the laser tube wall are spaced apart by a predetermined distance to form a passage for the electromagnetic wave. In this
15 structure, the wavefront of an electromagnetic wave emitted from each fine gap is flattened near the laser tube wall, so the electromagnetic wave propagates in the form of an approximately plane wave as a whole in the laser tube. Accordingly, an electromagnetic wave in the form of a
20 substantially uniform plane wave reaches a laser gas in the laser tube. This realizes uniform plasma discharge over the length of the laser tube and helps uniformize laser emission.

More specifically, the distance from the fine gaps to the laser tube wall is an integral multiple of the half-wave
25 length, in the tube, of an electromagnetic wave introduced from the waveguide. Consequently, an electromagnetic wave

emitted from each fine gap reaches the laser tube without interfering with a reflected wave or weakening each other.

Also, a conductor is so formed as to surround the passage including the fine gaps, and the passage is formed
5 as a gap having a predetermined width (preferably, an integral multiple of the half-wave length of the electromagnetic wave in the tube). This can minimize energy loss. Preferably, the width is an integral multiple of the half-wave length of the electromagnetic wave in the tube.
10 This makes it possible to give resonance conditions in a direction perpendicular to the fine gaps and set a high electric field in the slit.

Furthermore, by filling the gap with a dielectric member it is possible to prevent the generation of a plasma
15 in the passage and reliably bring about plasma discharge only in the laser tube.

A laser oscillating apparatus for achieving the above objects according to the present invention is a laser oscillating apparatus for exciting a laser gas in a laser
20 tube by introducing an electromagnetic wave from a waveguide into the laser tube through a plurality of fine gaps formed in a waveguide wall, and generating a laser beam by resonating light emitted from the laser gas, wherein the width of longitudinal end portions of the fine gap is made larger than
25 the width of a central portion thereof.

According to still another aspect of the laser oscillating apparatus of the present invention, the end portions have circular shapes with a diameter larger than the width of the central portion.

5 A laser oscillating apparatus according to the present invention is a laser oscillating apparatus for exciting a laser gas in a laser tube by introducing an electromagnetic wave from a waveguide into the laser tube through a plurality of fine gaps formed in a waveguide wall, and generating a
10 laser beam by resonating light emitted from the laser gas, wherein the fine gaps are formed apart from a central axis along a longitudinal direction of the waveguide, and each of the fine gaps is curved such that end portions are closer to the central axis than a central portion.

15 According to still another aspect of the laser oscillating apparatus of the present invention, the electromagnetic wave is radiated from the waveguide in the direction of a long end face of the waveguide.

 A laser oscillating apparatus according to the present
20 invention is a laser oscillating apparatus for exciting a laser gas in a laser tube by introducing an electromagnetic wave from a waveguide into the laser tube through a plurality of fine gaps formed in a waveguide wall, and generating a laser beam by resonating light emitted from the laser gas,
25 wherein an air-gap structure is formed in the waveguide wall in which the fine gaps are formed.

According to still another aspect of the laser oscillating apparatus of the present invention, in the vicinities of end portions of the fine gap, the air-gap structure is formed within a range from the end portions to
5 a distance of $\lambda g/4$ (λg is the waveguide wavelength of the electromagnetic wave).

According to still another aspect of the laser oscillating apparatus of the present invention, in the vicinities of end portions of the fine gap the air-gap
10 structure is formed within a range from the end portions to a distance of $\lambda g/2$ (λg is the waveguide wavelength of the electromagnetic wave).

According to still another aspect of the laser oscillating apparatus of the present invention, an air-gap
15 portion of the air-gap structure in a central portion of the fine gap is made smaller than an air-gap portion near end portions of the fine gap.

According to still another aspect of the laser oscillating apparatus of the present invention, in a
20 direction perpendicular to a longitudinal direction of the fine gap, the air-gap structure is formed with a width equal to an integral multiple of $\lambda g/2$ (λg is the waveguide wavelength of the electromagnetic wave).

A laser oscillating apparatus for achieving the above
25 objects according to still another aspect of the present invention is a laser oscillating apparatus for exciting a

laser gas in a laser tube by introducing an electromagnetic waves from a waveguide into the laser tube through a plurality of fine gaps formed in a waveguide wall, and generating a laser beam by resonating light emitted from the laser gas, wherein a dielectric lens or a structure substantially equivalent to a lens, for the electromagnetic wave, is formed in the waveguide in a portion close to the fine gap.

A laser oscillating apparatus according to the present invention is a laser oscillating apparatus for exciting a laser gas in a laser tube by introducing an electromagnetic waves from a waveguide into the laser tube through a plurality of fine gaps formed in a waveguide wall, and generating a laser beam by resonating light emitted from the laser gas, wherein the width of longitudinal end portions of the fine gap is made smaller than the width of a central portion thereof.

A laser oscillating apparatus for achieving the above objects according to the present invention is a laser oscillating apparatus for exciting a laser gas in a laser tube by introducing an electromagnetic wave from a waveguide into the laser tube through a plurality of fine gaps formed in a waveguide wall, and generating a laser beam by resonating light emitted from the laser gas, wherein the fine gap is formed in a portion where an emission characteristic of an electromagnetic wave depending on the fine gap is contrary

to an intensity distribution of an electromagnetic wave propagating in the waveguide.

According to still another aspect of the laser oscillating apparatus of the present invention, the fine gap
5 is formed such that a minimum value of an intensity distribution of an electromagnetic wave propagating in the waveguide is in substantially the center of the fine gap.

According to still another aspect of the laser oscillating apparatus of the present invention, the fine gaps
10 are formed in a line at a pitch equal to the waveguide wavelength or the half-wave length of an electromagnetic wave in the waveguide.

According to still another aspect of the present invention, an electromagnetic wave introduced from the
15 waveguide is a microwave.

In the laser oscillating apparatus of the present invention described above, each fine gap is formed in a portion where the emission characteristic of an electromagnetic wave from this fine gap is contrary to the
20 intensity distribution of an electromagnetic wave propagating in the waveguide. The emission characteristic of an electromagnetic wave depending upon the fine gap exhibits a distribution in which, as described above, the electromagnetic wave intensity is a maximum in the central
25 portion of the fine gap and decreases toward the end portions of the fine gap. Therefore, when each fine gap is formed in

a position where the intensity distribution of an electromagnetic wave propagating in the waveguide is contrary to this, the intensity distribution of the electromagnetic wave propagating in the waveguide is
5 influenced by the intensity distribution due to the emission characteristic of an electromagnetic wave depending on the fine gap. Consequently, the uniformity of the intensity distribution of an electromagnetic wave emitted from each fine gap actually increases over the whole region of each
10 fine gap.

More specifically, when fine gaps are to be formed in a line at a pitch equal to the guide wavelength, or its half-wave length, of an electromagnetic wave in the waveguide by assuming an E-plane antenna, each fine gap is so formed
15 that a minimum value of the intensity distribution of an electromagnetic wave propagating in the waveguide is positioned in substantially the center of the fine gap. That is, these fine gaps are formed in portions where they are equally deviated by $\lambda g/4$ (λg : the waveguide wavelength) from
20 positions at which a maximum value of the emission intensity distribution of an electromagnetic wave comes to the center of each fine gap in accordance with the intensity distribution of an electromagnetic wave propagating in the waveguide. By this relatively simple method, it is possible
25 to further uniformize the intensity distribution of an electromagnetic wave emitted from each fine gap.

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A laser oscillating apparatus for achieving the above objects according to still another aspect of the present invention is a laser oscillating apparatus for generating a plasma by exciting a laser gas in a laser tube by introducing
5 an electromagnetic wave from a waveguide into the laser tube through a plurality of fine gaps formed in a waveguide wall, and generating a laser beam by resonating light emitted from the plasma, comprising a shielding structure in the laser tube in order to prevent the plasma excited above the fine
10 gaps from diffusing from a predetermined region.

According to still another aspect of the laser oscillating apparatus of the present invention, the shielding structure is formed to prevent diffusion of the electromagnetic wave and the plasma in a direction
15 perpendicular to a longitudinal direction of the fine gaps.

According to still another aspect of the laser oscillating apparatus of the present invention, the shielding structure comprises a metal wall spaced apart from the fine gaps by a predetermined distance.

20 According to still another aspect of the laser oscillating apparatus of the present invention, the shielding structure is made from a mesh-like plate member.

According to still another aspect of the laser oscillating apparatus of the present invention, the
25 shielding structure comprises a plurality of nozzles having predetermined openings.

laser beam by resonating light emitted from the plasma,
wherein each of the fine gaps comprises a plurality of rows
of slits.

According to still another aspect of the laser
5 oscillating apparatus of the present invention, the width
of slits in end rows is smaller than the width of slits in
rows near the center.

According to still another aspect of the laser
oscillating apparatus of the present invention, the length
10 of slits in end rows is smaller than the length of slits in
rows near the center.

According to still another aspect of the laser
oscillating apparatus of the present invention, a shielding
structure for suppressing diffusion of the plasma is formed
15 on the side of an opening edge of the fine gap facing the
laser tube.

A laser oscillating apparatus for achieving the above
objects according to still another aspect of the present
invention is a laser oscillating apparatus for exciting a
20 laser gas in a laser tube by introducing an electromagnetic
wave from a waveguide into the laser tube through a plurality
of fine gaps formed in a waveguide wall, and generating a
laser beam by resonating light emitted from the laser gas,
comprising a pair of waveguides formed to sandwich the laser
25 tube such that formation surfaces of the fine gaps oppose
each other, identical electromagnetic waves being supplied

to the pair of waveguides to excite a laser gas in two opposite directions in the laser tube. In this apparatus, the pair of waveguides are constructed such that intensity distributions of electromagnetic waves introduced therefrom are shifted from each other.

According to still another aspect of the laser oscillating apparatus of the present invention, the formation surfaces of the fine gaps are short-end faces of the waveguides, and the fine gaps are formed in a line at equal intervals in a longitudinal direction of the fine gaps.

According to still another aspect of the laser oscillating apparatus of the present invention, the waveguides are arranged such that fine gaps corresponding to each other between the opposing formation surfaces are shifted relative to each other by a predetermined distance.

According to still another aspect of the laser oscillating apparatus of the present invention, the apparatus further comprises phase adjusting means for shifting phases of electromagnetic waves supplied into the waveguides relative to each other.

According to still another aspect of the laser oscillating apparatus of the present invention, each of the waveguides comprises tuning means for tuning an electromagnetic wave.

According to still another aspect of the laser oscillating apparatus of the present invention, an

electromagnetic wave introduced from the waveguide is a microwave.

In the laser oscillating apparatus of the present invention described above, a pair of waveguides are so formed
5 as to sandwich the laser tube such that the formation surfaces of the fine gaps (slots) oppose each other, and laser gas excitation is performed in two opposite directions in the laser tube. In accordance with various demands, the spatial positions of the two waveguides are adjusted such that the
10 fine gaps in the opposing formation surfaces are shifted a predetermined distance relative to each other. Alternatively, the phases of electromagnetic waves supplied to these waveguides are shifted relative to each other. Consequently, variations of the wavefront of an
15 electromagnetic wave resulting from the discontinuity of the fine gaps compensate for each other, so the light emission region substantially increases to flatten the wavefront. Accordingly, an electromagnetic wave substantially uniformly reaches the whole of a laser gas in the laser tube.
20 This realizes uniform plasma discharge over the length of the laser tube and helps uniformize laser emission.

According to still another aspect of the present invention, the above laser oscillating apparatus is an excimer laser oscillator in which the laser gas is at least
25 one inert gas selected from Kr, Ar, and Ne or a gas mixture of this inert gas and F_2 gas.

reference characters designate the same or similar parts throughout the figures thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are incorporated in
5 and constitute a part of the specification, illustrate
embodiments of the invention and, together with the
description, serve to explain the principles of the
invention.

Fig. 1 is a schematic view showing the major components
10 of an excimer laser oscillator according to the first
embodiment;

Figs. 2A and 2B are schematic views showing a practical
structure of a waveguide according to the first embodiment;

Figs. 3A and 3B are schematic sectional views showing
15 a practical structure of the waveguide;

Fig. 4 is a view showing the relationship between the
slot positions in the waveguide and the current density
produced by a microwave;

Fig. 5 is a schematic sectional view showing the way
20 a microwave is emitted from slots;

Figs. 6A and 6B are schematic sectional views showing
a practical structure of a waveguide in Modification 1;

Fig. 7 is a schematic sectional view showing a
practical structure of a waveguide in Modification 2;

25 Fig. 8 is a schematic sectional view showing a
practical structure of the waveguide in Modification 2;

Figs. 9A and 9B are schematic sectional views showing a practical structure of a waveguide in Modification 3;

Fig. 10 is a schematic plan view showing a practical structure of another waveguide in Modification 3;

5 Fig. 11 is a schematic sectional view showing a practical structure of a waveguide in Modification 4;

Fig. 12 is a schematic sectional view showing a practical structure of still another waveguide in Modification 4;

10 Figs. 13A and 13B are schematic views showing a practical structure of a waveguide in Modification 5;

Fig. 14 is a schematic view showing the main components of an excimer laser oscillator according to the second embodiment;

15 Figs. 15A and 15B are schematic views showing a practical structure of a waveguide of the excimer laser oscillator according to the second embodiment;

Figs. 16A to 16D are schematic views showing a slot according to the second embodiment and radiation energy;

20 Figs. 17A to 17C are schematic views showing a slot according to the second embodiment and radiation energy;

Figs. 18A to 18C are schematic views showing a slot according to the second embodiment and radiation energy;

25 Figs. 19A to 19C are schematic views showing electric currents generated in a waveguide wall by a microwave on the E and H planes;

Figs. 20A and 20B are views showing a slot according to the third embodiment and the arrangement of slots in a waveguide;

5 Figs. 21A and 21B are schematic views showing other shapes of the slot according to the third embodiment;

Figs. 22A and 22B are schematic views showing other shapes of the slot according to the third embodiment;

Fig. 23 is a schematic view showing still another shape of the slot according to the third embodiment;

10 Figs. 24A and 24B are schematic views showing an air-gap structure according to the fourth embodiment;

Figs. 25A and 25B are schematic views showing another air-gap structure according to the fourth embodiment;

15 Figs. 26A and 26B are schematic views showing still another air-gap structure according to the fourth embodiment;

Figs. 27A and 27B are perspective views showing waveguides and slots according to the fourth embodiment;

20 Figs. 28A to 28C are schematic sectional views showing the shapes of slots according to the fourth embodiment;

Fig. 29 is a schematic view showing the relationship between the slot formation portions in a waveguide and the density of a current flowing through the wall surface of the waveguide according to the fifth embodiment;

25 Fig. 30 is a graph showing the intensity distribution of a microwave emitted from a slot;

Fig. 31 is a schematic view showing the relationship between the slot formation portions in a waveguide and the density of a current flowing through the wall surface of the waveguide according to a modification of the fifth

5 embodiment;

Figs. 32A to 32C are graphs showing the relationships between the slot positions of slots formed in a waveguide and the radiation energy or the standing wave intensity according to the fifth embodiment;

10 Figs. 33A and 33B are schematic views showing a practical structure of a waveguide of an excimer laser oscillator according to the fifth and sixth embodiments;

Figs. 34A and 34B are schematic views showing shielding structures in the laser oscillating apparatus according to
15 the sixth embodiment;

Figs. 35A and 35B are schematic views showing a shielding structure in the laser oscillating apparatus according to the seventh embodiment;

Figs. 36A and 36B are schematic views showing shielding
20 structures in a laser oscillating apparatus according to the seventh embodiment;

Figs. 37A and 37B are schematic views showing shielding structures in a laser oscillating apparatus according to the eighth embodiment;

Figs. 38A and 38B are schematic views showing shielding structures in the laser oscillating apparatus according to the eighth embodiment;

Fig. 39 is a schematic sectional view showing a shielding structure in the laser oscillating apparatus according to the eighth embodiment;

Fig. 40 is a schematic sectional view showing a slot in a laser oscillating apparatus according to the ninth embodiment;

Fig. 41 is a schematic plan view showing slots in the laser oscillating apparatus according to the ninth embodiment;

Fig. 42 is a schematic sectional view showing a slot in a laser oscillating apparatus according to the 10th embodiment;

Fig. 43 is a schematic view showing a slot in the laser oscillating apparatus according to the 10th embodiment;

Fig. 44 is a schematic plan view showing a slot in the laser oscillating apparatus according to the 10th embodiment;

Fig. 45 is a schematic view showing the major parts of an excimer laser oscillator according to the 11th embodiment;

Fig. 46 is a perspective view showing the slot formation surface (E plane) of a waveguide;

Fig. 47 is a graph showing the relationship between the standing waves of a microwave when space shift and phase shift are performed;

Fig. 48 is a schematic view showing waveguides normally arranged in the excimer laser oscillator according to the 11th embodiment;

Figs. 49A and 49B are schematic views showing the waveguides when $\lambda g/2$ space shift and $\lambda g/2$ phase shift are performed at a pitch of λg in the excimer laser oscillator according to the 11th embodiment;

Fig. 50 is a perspective view showing the slot formation surface (H plane) in the waveguide;

Fig. 51 is a schematic view showing the waveguides normally arranged in a modification of the excimer laser oscillator according to the 11th embodiment;

Fig. 52 is a schematic view showing a stepper according to the 12th embodiment;

Fig. 53 is a flow chart showing semiconductor device fabrication steps using the stepper according to the 12th embodiment;

Fig. 54 is a flow chart showing details of a wafer process shown in Fig. 53;

Fig. 55 is a schematic sectional view showing a practical structure of a general waveguide;

Fig. 47 is a graph showing the relationship between the standing waves of a microwave when space shift and phase shift are performed;

Fig. 48 is a schematic view showing waveguides normally
5 arranged in the excimer laser oscillator according to the 11th embodiment;

Figs. 49A and 49B are schematic views showing the waveguides when $\lambda g/2$ space shift and $\lambda g/2$ phase shift are performed at a pitch of λg in the excimer laser oscillator
10 according to the 11th embodiment;

Fig. 50 is a perspective view showing the slot formation surface (H plane) in the waveguide;

Fig. 51 is a schematic view showing the waveguides normally arranged in a modification of the excimer laser
15 oscillator according to the 11th embodiment;

Fig. 52 is a schematic view showing a stepper according to the 12th embodiment;

Fig. 53 is a flow chart showing semiconductor device fabrication steps using the stepper according to the 12th
20 embodiment;

Fig. 54 is a flow chart showing details of a wafer process shown in Fig. 53;

Fig. 55 is a schematic sectional view showing a practical structure of a general waveguide;

Figs. 56A and 56B are graphs showing the intensity distributions of a microwave emitted from a slot in the general waveguide; and

Fig. 57 is a schematic sectional view for explaining a sheath formed on a slot in a general laser oscillating apparatus.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of the present invention will now be described in detail in accordance with the accompanying drawings.

(First Embodiment)

The first embodiment will be described below. In this embodiment, an excimer laser oscillator which emits a so-called excimer laser beam will be explained. Fig. 1 is a schematic view showing the main parts of the excimer laser oscillator of this embodiment.

As shown in Fig. 1, this excimer laser oscillator includes a laser tube 2, waveguide 1, and cooling vessel 7. The laser tube 2 emits a laser beam by resonating light emission due to excitation of an excimer laser gas. The waveguide 1 excites the excimer laser gas in the laser tube 2 to generate a plasma. The cooling vessel 7 has cooling water inlet/output ports 9 for cooling the waveguide 1.

The excimer laser gas as a material for generating an excimer laser beam is at least one inert gas selected from

Kr, Ar, Ne and He, or a gas mixture of at least one inert gas described above and F_2 gas. These gases can be appropriately selected and used in accordance with the wavelength of interest. For example, KrF is used when a laser beam with a wavelength of 248 nm is to be generated; ArF_2 is used when a laser beam with a wavelength of 193 nm is to be generated; and F_2 is used when a laser beam with a wavelength of 157 nm is to be generated. Also, Kr_2 is used when a laser beam with a wavelength of 147nm is to be generated, $ArKr$ is used when a laser beam with a wavelength of 134 nm is to be generated, and Ar_2 is used when a laser beam with a wavelength of 126nm is to be generated.

The laser tube 2 has laser gas inlet/output ports 8 through which the excimer laser gas is introduced into the tube, and reflecting structures 5 and 6 at the two end portions. These reflecting structures 5 and 6 equalize the phases of light by plasma discharge and generate a laser beam.

The waveguide 1 is a means for supplying a microwave to the laser gas in a gas supply passage structure 11. As shown in Fig. 1, a plurality of long and narrow slots 10 are formed in the upper surface. When a microwave with a frequency of a few hundred MHz to several tens of GHz is introduced from the lower portion of the waveguide 1 shown in Fig. 1, this microwave propagates in the waveguide 1 and is emitted from the slots 10 to the outside of the waveguide 1. The emitted microwave is introduced into the laser tube

2 through a window 15 formed in this laser tube 2. The microwave thus introduced excites the excimer laser gas in the laser tube 2, thereby generating an excimer laser beam by resonance.

5 In this embodiment, the waveguide 1 has a conductor plate, i.e., a metal wall 12 (Figs. 2A, 2B, 3A, and 3B), in a portion between the waveguide wall and the laser tube wall. This metal wall 12 separates the waveguide wall from the laser tube wall by a predetermined distance.

10 Figs. 2A, 2B, 3A, and 3B show practical structures of the waveguide 1. Fig. 2A is a schematic perspective view of the waveguide 1. Fig. 2B is a plan view of the waveguide 1. Fig. 3A is a sectional view taken along a line II - II' of Fig. 2B. Fig. 3B is a sectional view taken along a line I
15 - I' of Fig. 2B.

 As shown in Fig. 2B, the slots 10 are arranged in a line such that their longitudinal direction is consistent with the longitudinal direction of the waveguide 1. The metal wall 12 is so formed as to surround these slots 10.
20 As shown in Fig. 3A, between the slots 10 and the window 15 in the laser tube wall, this metal wall 12 forms a space which covers the entire area of the waveguide 1 in the longitudinal direction of the laser tube 2. This space is a microwave passage 11.

25 In this embodiment, the slots 10 are formed in a so-called E plane of the waveguide 1. To form the slits 10

in an H plane, a metal wall must be formed so that a passage corresponding to the formation portion of the slits 10 is formed.

The E plane is a plane parallel to the direction of
5 the electric field of a TE₁₀ modemicrowave. The H plane is a plane perpendicular to this microwave field direction.

The distance from the slots 10 to the window 15 of the laser tube wall is an integral multiple of the waveguide half-wave length of a microwave introduced from the waveguide
10 1, i.e., is a distance d represented by

$$d = n \times \lambda_g / 2 \quad \dots (1)$$

where λ_g is the waveguide wavelength of a microwave, and n is an integer.

Accordingly, the passage 11 functions as a resonator
15 to prevent a microwave emitted from each slot 10 from interfering with a reflected wave from the laser tube 2 and weakening each other.

The integer n can take any arbitrary value. However, if this value is too large, when a microwave propagates in
20 the passage 11, the loss by absorption of the microwave to the metal wall 12 increases, as will be described later. Hence, the integer n is most preferably set to about 1 to 3 as will be explained later.

For the same reason as above, the width of the passage
25 11 is an integral multiple of the waveguide half-wave length

of a microwave introduced from the waveguide 1, i.e., is a width w represented by

$$w = n \times \lambda g/2 \quad \dots (2)$$

The function of the waveguide 1 including the passage 11 will be described below.

When a microwave propagates in the waveguide 1, an electric current flows through the waveguide wall. A microwave exists as a standing wave in a propagation space defined by the distance in the longitudinal direction of the waveguide 1. Owing to this standing wave, the current in the waveguide wall also takes the form of a standing wave. However, the form of the standing wave of a microwave is three-dimensional and complicated. Therefore, it is convenient to consider, as an index, the standing wave of an electric current in a general distributed constant line.

Fig. 4 shows an example using the current standing wave described above as an index. In this example, the slots 10 are formed so that their formation portions correspond to the antinodes of the standing wave of a current (i.e., the standing wave of a microwave). Accordingly, as shown in Fig. 5, immediately after the microwave is emitted from the slots 10, the wavefront of the microwave assumes a discontinuous curved shape corresponding to the slots 10 owing to the array structure of the slots 10. The microwave gradually approaches a plane wave as it propagates, from each slot 10, in the passage 11 regulated by the metal wall 12.

When the microwave is emitted outside (i.e., into the laser tube) through the passage 11, its wavefront assumes a substantially plane-wave shape over the entire formation region of the slots 10.

5 Accordingly, a microwave in the form of a substantially uniform plane wave reaches the excimer laser gas in the laser tube 2. This realizes uniform plasma discharge over the length of the laser 2 and helps uniformize laser emission.

Modifications of the first embodiment will be
10 described below. Note that the same reference numerals as in the above embodiment denote the same parts, and a detailed description thereof will be omitted.

(Modification 1)

In this Modification 1, as shown in Figs. 6A and 6B
15 (sectional views similar to Figs. 3A and 3B), the metal wall 12 is formed such that only an end portion 13 of the passage 11 is narrowed. This end portion 13 of the passage 11 is slit over the length of the laser tube 2 in a portion (i.e., the window 15) where the end portion 13 is in contact with the
20 laser tube 2.

When the passage 11 is formed into this shape, unintentional energy scattering can be further suppressed when a microwave is emitted into the laser tube 2.

(Modification 2)

25 In this Modification 2, the passage 11 is filled with a dielectric member 14 as shown in Figs. 7 and 8 in the

structures shown in Figs. 3A and 6A, respectively. Suitable materials of this dielectric member 14 are quartz, calcium fluoride, aluminum nitride, alumina, and zirconia.

By filling the passage 11 with the dielectric member 14, the generation of a plasma in the passage 11 can be prevented. This dielectric member 14 used desirably has a high dielectric constant and a small dielectric loss for more efficient propagation of a microwave.

Furthermore, the dielectric member 14 can be composed of a plurality of different members made from a plurality of different dielectric substances having different dielectric constants. That is, when the resistance against fluorine gas or a plasma having high reactivity or the transmittance of a microwave is taken into consideration, the dielectric member shown in Fig. 7 can be composed of a plurality of different dielectric substances having different physical characteristics or different dielectric constants. For example, the end portion 13 and the other portion of the dielectric member 14 shown in Fig. 8 can be constructed of a plurality of different dielectric substances having different dielectric constants.

To rapidly emit large amounts of heat simultaneously generated in plasma to the outside, the dielectric member 14 is required to have high thermal conductivity. Additionally, since the dielectric member 14 is exposed to an ambient, such as an excimer laser, containing F_2 which is

highly reactive and the like, it is important for this dielectric member 14 to have high resistance against corrosive gases. The surface in contact with the emission end of a microwave, i.e., a plasma is in very severe environment at a high temperature of 100 to 1,000°C (depending on the incident energy) plus sputtering by ion irradiation of a few eV to a few hundred eV (depending on the plasma potential) from the plasma. Accordingly, AlN or alumina having high thermal conductivity and a relatively high F_2 resistance is used as the material of the dielectric member 14. Also, the surface (the interface with the plasma) of this dielectric member 14 is coated with a fluoride, such as CaF_2 , LiF_2 , AlF_3 or MgF_2 , having a thickness of a few μm to a few hundred μm . Consequently, it is possible to simultaneously achieve high thermal conductivity, high resistance to corrosive gases, and high sputtering resistance.

The energy loss in the passage 11 is roughly divided into two losses: dielectric loss in the packed dielectric member and loss on the waveguide wall. An attenuation constant α by the dielectric loss is represented by

$$\alpha = \omega \mu \sigma / 2 \beta \quad \dots (3)$$

(ω : angular frequency/ μ : permeability/ σ : electrical conductivity/ β : phase constant). Focusing attention on the

25 TE₁₀ mode, the loss on the waveguide wall is given by

$$\alpha = \frac{1}{\xi_b \delta \sigma} \frac{1 + \frac{2b}{a} \left(\frac{\lambda}{2a} \right)^2}{\sqrt{1 - \left(\frac{\lambda}{2a} \right)^2}}$$

(ξ : electric wave impedance/ δ : skin depth)

The dominating one of these two losses need only be smaller than the energy supplied by a plasma. That is, letting r be the absorptivity of microwaves by a plasma, $r \ll 1$. When round trip (multiple reflection) between the slot surface and the plasma interface is taken into consideration, the maximum length of the uniformized line can be defined by using n meeting

$$\exp(-2\alpha \cdot n\lambda g/2) < r \quad \dots (4)$$

In respect of the efficiency of a microwave, however, it is important to set the loss to be as small as possible compared to the absorption r . It is preferable to design the loss to be about 1/10 to 1/100 of r (with this design, a system having smaller loss can be designed).

A practical experiment conducted by filling the passage 11 with the dielectric member 14 will be described below.

An E-surface emission antenna having $a = 42$ mm, $b = 21$ mm, and a waveguide resonator length (in the longitudinal direction, i.e., the laser oscillation direction) of 220.8 mm was used to manufacture a 2.45-GHz microwave emission antenna having an Al alloy housing in which the metal wall 12 was formed in front of the slots. A waveguide resonator,

i.e., the passage 11 was filled with alumina with a dielectric constant of 9.8. The wavelength in the waveguide resonator was 44.2 mm. Accordingly, the slot pitch was also set to 44.2 mm.

5 A microwave emitted from the slots was emitted into the passage 11. This passage 11 was approximately a parallel-plate waveguide. Under the approximation, the wavelength was 39.1 mm, equal (inside the dielectric member) to the wavelength in a free space. In effect, the waveguide
10 was a rectangular waveguide whose a was a length of 235.3 mm in the laser oscillation direction of the passage 11. The waveguide wavelength was 39.2 mm, different from the wavelength in a free space by only about 3.5×10^{-3} . Hence, in this structure wavelength approximation of the free space
15 length is also usable. The half-wave length was 19.6 mm. The distance from the slot surface 10 of the passage 11 to the emission surface was given by 19.6 mm, 39.2 mm, 58.8 mm, ..., for n : 1, 2, 3,

 Loss in the resonator will be considered below. α by
20 the dielectric loss was 5.22×10^{-7} dB/m when the resistivity of alumina was $10^{-11} \Omega \cdot \text{cm}$. The loss by waveguide wall absorption was 0.234 dB/m when the resistivity of alumina was $2.65 \times 10^{-6} \Omega \cdot \text{cm}$. In this case, the dominating loss was the absorption by the wall. Therefore, a loss of 0.053% was
25 produced with respect to energy propagating in the waveguide for each progress of 19.6 mm. Accordingly, to suppress loss

caused by round trip in the passage 11 to be about 0.2% of the input energy, n was set to 1 to 3 which was smaller than 4 (loss: 0.21%) and by which the best uniformizing effect was obtained. Since multiple reflection occurs in practice, it is necessary to suppress to this low loss level.

(Modification 3)

In this Modification 3, as shown in Figs. 9A and 9B (sectional views similar to Figs. 3A and 3B), only the end portion 13 of the passage 11 is widened. More specifically, the metal wall 12 is formed so that the passage 11 has a wide portion 16 whose half-width α satisfies $\alpha = \lambda g/4$ or $\alpha = \lambda g/2$.

In this structure, the wide portion 16 is formed by the passage 11 over the entire area of the waveguide 1 in the longitudinal direction of the laser tube 2. Since this wide portion 16 is formed to have the width as described above, the resonance energy of a microwave can be efficiently concentrated in this wide portion 16.

As in Modification 2 described above, a dielectric member with which the wide portion 16 shown in Figs. 9A and 9B is filled can be made from a material having a different dielectric constant from that of a dielectric member in the other portion.

A waveguide was manufactured by adding this structure to the waveguide having the structure explained in Modification 2. α was 19.6 mm and 39.2 mm for $\lambda g/4$ and λ

$g/2$, respectively, and the height of the wide portion 16 was 5 mm. The thickness of the passage 11 was 4 mm. Energy existing in the wide portion 16 was 31.3% and 47.7% of energies existing in the passage 11 and the wide portion 16,

5 respectively. This indicates that energy was concentrated into a portion (i.e., the wide portion 16) close to the window 15. This comparison seems to demonstrate that energy was more concentrated when α was $\lambda g/2$. However, the energy of a microwave existing within a distance of $\lambda g/4$ from the
10 center of the wide portion 16 (i.e., in the vicinity of a slot 10) was 31.3% and 23.8% of energies existing in the passage 11 and the wide portion 16, respectively. Therefore, the effect of concentrating energy to the vicinity of the slot 10 was larger when α was $\lambda g/4$.

15 Another form of Modification 3 is shown in Fig. 10. In this structure, the width of the wide portion 16 is changed along the longitudinal direction of the laser tube 2 by reflecting the intensity distribution of a microwave emitted from the slot 10. That is, in addition to forming the passage
20 11 by forming the metal wall 12, the width (or the half-width α) of the wide portion 16 is changed in accordance with the nonuniformity in a microwave emission portion of the passage 11 to further improve the uniformity, in order to uniformize the wavefront of a microwave.

25 Consequently, a microwave formed into a more uniform plane wave reaches the excimer laser gas in the laser tube

2. This realizes uniform plasma discharge over the length of the laser tube 2 and contributes to further uniformization of laser emission.

This effect is due to the intrinsic property of
5 microwaves by which the characteristics of a propagation path can be changed by changing a spatial gap shape. Impedance Z of a terminally short-circuited waveguide with length L and characteristic impedance Z_0 is

$$Z = jZ_0 \tan(2\pi \cdot L / \lambda_g)$$

10 This shows that an inductive element (an inductance or coil as a discrete element) and a capacitive element (a capacitance or capacitor as a discrete element) having any arbitrary value can be formed by only changing L . Changing the half-width α in the slot line direction is equivalent,
15 for an electromagnetic wave, to additionally changing the impedance of a slot (in equivalent circuit, coils and capacitors having various values are connected in parallel with a slot). As a consequence, the distribution of an electromagnetic wave emitted from the slot can be controlled.

20 (Modification 4)

In this Modification 4, as shown in Fig. 11, on each slot 10 in the passage 11, a dielectric lens 17 having a symmetrical curved surface with respect to the slot 10 is formed. This curved surface shape can be a combination of
25 a spherical surface, an aspherical surface (e.g., an elliptic or hyperbolic shape), and a rectangular shape in accordance

distances in the passage 11, and their curved surfaces are aspherical surfaces.

In Figs. 11 and 12, when the passage 11 is filled with a dielectric member, a similar effect can naturally be achieved by forming gaps having the shapes of the dielectric lenses 17 and 18 in the dielectric member in the passage 11, instead of forming the dielectric lenses 17 and 18.

(Modification 5)

In this Modification 5, as shown in Figs. 13A and 13B (identical with Figs. 3A and 3B), the waveguide 1 is filled with a dielectric member 19. Letting λ_c be the cutoff frequency, the relationship between wavelength λ and waveguide wavelength λ_g of a microwave emitted is represented by

15
$$\lambda_g = \frac{1}{\sqrt{(1/\lambda)^2 - (1/\lambda_c)^2}}$$

That is, in E-plane radiation the interval between slots 10 is λ_g or $\lambda_g/2$. Therefore, when the waveguide 1 is filled with a dielectric member having a high dielectric constant and if this dielectric member 19 is not a ferromagnetic member, the wavelength λ decreases in inverse proportion to the square of the dielectric constant, and the pitch of the waveguide wavelength λ_g narrows. This allows a more uniform emission of microwaves.

Examples of usable dielectric substances are as shown in Table 1 below. However, dielectric loss generally

increases when a dielectric constant increases, so the material must be chosen by taking this into consideration.

Table 1

	Dielectric constant	Ratio[%] of wavelength λ normalized in the absence of dielectric substance
Air	1	1.000
Quartz	3.6	0.527
Calcium fluoride	6.76	0.385
Aluminum nitride	8.8	0.337
Alumina	9.8	0.319
Zirconia	12.5	0.283

5

When the waveguide 1 is filled with these dielectric substances, the guide wavelength of in the waveguide 1 decreases at the wavelength ratios described in Table 1.

This makes it possible to sufficiently uniformize the

10 wavefront of a microwave.

(Modification 6)

In this Modification 6, a microwave with a frequency of about 4.9 GHz is used to double the pitch in the waveguide 1 having high frequency, e.g., 2.45 GHz. Consequently, the
15 wavelength λ changes in inverse proportion to this frequency, and this narrows the pitch of the slots 10.

(Modification 7)

In this Modification 7, the H-plane width of the waveguide 1 is made as large as possible. As a cutoff frequency λ_c of the waveguide 1 is increased within the range
5 in which microwaves of an excitation frequency band are not cut off, the waveguide wavelength λ_g approaches the wavelength λ . Accordingly, when only the TE₁₀ mode propagates in the waveguide 1, the pitch of the slots 10 can be narrowed by making the H-plane width as large as possible.
10 The condition by which only the TE₁₀ mode propagates is a $< \lambda$ ($< 2a$) where a is the H-plane width, so this H-plane width is given by $(\lambda/2 <) a < \lambda$. The term in () is the condition which eliminates the conditions by which microwaves of all modes cannot propagate. Therefore, by setting the H-plane
15 width a to about the wavelength λ , the waveguide wavelength λ_g can be set to a minimum value $2/3^{1/2} \lambda$ ($\approx 1.15 \lambda$). Note that when multi-mode excitation is permitted, the waveguide wavelength λ_g approaches the minimum value λ . However, this is unrealistic because $a \rightarrow \infty$ in this case.

20 As described above, the excimer laser oscillators according to this embodiment and its modifications employ a slot array structure and yet realize electromagnetic wave radiation uniform as a whole over the length of a laser tube and allow uniform laser emission with minimum energy loss.

25 In the first embodiment as described above, although a slot array structure is used, it is possible to realize

electromagnetic wave radiation uniform as a whole over the length of a laser tube and emit uniform a laser beam with minimum energy loss.

(Second Embodiment)

5 The second embodiment will be described next. Fig. 14 is a view showing a laser oscillating apparatus according to the second embodiment. In Fig. 14, the same reference numerals as in Fig. 1 denote parts having the same functions.

10 A waveguide 1 is a means for supplying a microwave to a laser gas in a gas supply passage structure 11. A plurality of long and narrow slots 10 are formed in the upper surface in Fig. 14. When a microwave with a frequency of a few hundred MHz to several tens of GHz is introduced from the upper portion of the waveguide 1, this microwave propagates in the
15 waveguide 1 and is emitted from the slots 10 to the outside of the waveguide 10. The emitted microwave is introduced into a laser tube 2. The microwave thus introduced excites an excimer laser gas in the laser tube 2, thereby emitting an excimer laser beam by resonance.

20 Figs. 15A and 15B show a practical structure of the waveguide 1 according to the second embodiment. Fig. 15A is a schematic perspective view of the waveguide 1. Fig. 15B is a plan view of the waveguide 1.

25 As shown in Fig. 15B, the slots 10 are arranged in a line such that their longitudinal direction is consistent with the longitudinal direction of the waveguide 1. These

slots 10 are arranged along the longitudinal direction of the waveguide 1, and each slot 10 has a shape extending in the longitudinal direction of the waveguide 1. In this second embodiment, the present invention is applied to the slot 10 which emits a microwave emitted from the E plane as the short end face of the waveguide 1.

Fig. 19A is a schematic view showing electric currents generated on the inner wall surface of the waveguide 1. As shown in Fig. 19A, electric currents are generated in a direction perpendicular to the slots 10 on the inner wall surface of the waveguide 1. Fig. 19C is a schematic view showing the E and H planes of the waveguide 1. The E plane is the short end face (the surface parallel to the direction of an electric field generated by a microwave) of the waveguide 1. The H plane is the long end face (the surface perpendicular to the direction of an electric field generated by a TE₁₀ mode microwave) of the waveguide 1.

Fig. 16A is a schematic plan view showing the shape of one arbitrary slot 10. As shown in Fig. 16A, the slot 10 widens toward its end portions in the longitudinal direction.

Fig. 16C is a graph showing the relationship between the longitudinal position on the slot 10 shown in Fig. 16A and the aperture ratio of the slot 10. As shown in Figs. 16A and 16C, the aperture ratio increases toward the end portions of the slot 10.

Fig. 16D is a graph showing the intensity of radiation energy when a microwave is radiated through the slot 10 shown in Fig. 16A. As shown in Fig. 16D, radiation energy in particularly the end portions of the slot 10 can be increased
 5 by the use of the slot 10 having a large aperture ratio in its end portions. That is, by changing the width of the slot 10 with respect to the current density across the slot 10 as shown in Fig. 16B, the radiation energy of a microwave emitted can be controlled in each longitudinal portion of
 10 the slot 10. Consequently, uniform radiation as shown in Fig. 16D is realized.

Note that the distribution of a microwave in actual emission is very difficult to measure or analyze owing to interference with a plasma and the like. Accordingly, in Fig.
 15 16D, the uniformity is evaluated by evaluating the uniformity from a slit with no plasma being excited.

This slot 10 having a centrally symmetrical shape is suitably used for microwaves emitted to the E plane by which the density distribution of an electric current is
 20 symmetrical in the short-axis direction of the slot 10.

As described above, the width of the slot 10 is changed along its longitudinal direction; the width in the end portions along the longitudinal direction is made larger than that in the central portion. Accordingly, the radiation of
 25 a microwave can be increased particularly in the end portions

of the slot 10. This makes uniform microwave emission as shown in Fig. 16D feasible.

Fig. 17A is a schematic plan view showing another example of the shape of the slot 10. The two end portions
5 in the longitudinal direction of this slot 10 shown in Fig. 17A are locally widened circularly into the shape of a dumbbell.

Fig. 17B is a graph showing the relationship between the longitudinal position on the slot 10 shown in Fig. 17A
10 and the aperture ratio of the slot 10. As shown in Figs. 17A and 17B, the aperture ratio increases in the end portions of the slot 10.

Fig. 17C is a graph showing the intensity of radiation energy when a microwave is emitted through the slot 10 shown
15 in Fig. 17A. As shown in Fig. 17C, by the use of the slot 10 having a large aperture ratio in the end portions, it is possible to enhance the emission of a microwave in circular portions 10a and increase the radiation energy particularly in the end portions of the slot 10. That is, by changing the
20 width of the slot 10 with respect to the current density across the slot 10 as shown in Fig. 19A, the intensity of a microwave emitted can be controlled in each longitudinal portion of the slot 10. This realizes uniform radiation as shown in Fig. 17C.

25 Also, the length of the slot 10 can be equivalently increased by increasing the radius r by adding a circle with

the radius r to each end of the slot 10. Consequently, Q can be decreased without substantially setting the slot length to $\lambda g/2$. Furthermore, since the end portions of the slot 10 are circular, mechanical processing for forming the slot 10 can be easily and precisely performed.

Fig. 18A shows a slot 10 having a shape connecting the two circles of the slot 10 shown in Fig. 17A with smoother curves.

Fig. 18B is a graph showing the relationship between the longitudinal position on the slot 10 shown in Fig. 18A and the aperture ratio of the slot 10. As shown in Figs. 18A and 18B, the aperture ratio increases toward the end portions of the slot 10.

Fig. 18C is a graph showing the intensity of radiation energy when a microwave is radiated through the slot 10 shown in Fig. 18A. As shown in Fig. 18C, by the use of the slot 10 having a large aperture ratio in the end portions, it is possible to enhance the emission of a microwave in circular portions 10a and increase the radiation energy particularly in the end portions of the slot 10. This realizes uniform radiation as shown in Fig. 18C.

The slot 10 shown in Fig. 18A has the circular end portions similar to those of the slot 10 shown in Fig. 17A. Hence, it is possible to equivalently increase the length of the slot 10 and easily and precisely perform mechanical processing.

such that the aperture in the end portions of the slot 10 increases. This makes it possible to increase the intensity of microwaves radiated from the end portions of the slot 10. Accordingly, uniform radiation of microwaves is possible in
5 the entire region on the slot 10.

(Third Embodiment)

The third embodiment of the present invention will be described below. In this third embodiment, the present invention is applied to a slot which emits microwaves from
10 the long end face (H plane) of a waveguide 1. Note that the overall structure of an excimer laser oscillator according to the third embodiment is identical with the second embodiment, so a detailed description thereof will be omitted. Note also that in the drawings for explaining the third
15 embodiment, the same reference numerals as in the second embodiment denote substantially the same parts, and a detailed description thereof will be omitted.

Fig. 19B is a schematic view showing the directions of electric currents generated in the waveguide wall by a
20 microwave on the H plane. As shown in Fig. 19B, each electric current flowing along the inner wall surface of the waveguide on the H plane flows from a node in the center of the width in a direction perpendicular to the longitudinal direction of the waveguide 1 toward a node separated by $\lambda g/2$.

25 Hence, when slots 10 are alternately formed at a pitch of $\lambda g/2$ in positions apart by d from a central line (an

alternate long and short dashed line C) of the width in the direction perpendicular to the longitudinal direction of the waveguide 1, radiations from all the slots 10 are in phase with each other.

5 Figs. 20A and 20B show the shape of a slot 10 suitably used for microwaves emitted from the H plane. As explained in Fig. 19B, electric currents generated by a microwave are radially emitted from a node. So, a direction along which the slot 10 extends is made perpendicular to the current
10 directions. That is, when the slots 10 having the shape shown in Fig. 20A are formed in positions shown in Fig. 20B, the extending directions of these slots 10 can be made perpendicular to the current directions. This allows efficient emission of a microwave from these slots 10.

15 Figs. 21A and 21B are plan views showing other examples of the shape of the slot 10 used for the H plane. A slot 10 shown in Fig. 21A has an increased opening width in its end portions. Therefore, by forming these slots 10 in the positions shown in Fig. 20B, the radiation of a microwave
20 in the end portions of the slot 10 can be increased. Consequently, it is possible to uniformize the intensity of a microwave radiated above the slot 10.

 A slot 10 shown in Fig. 21B has a larger opening width in the central portion than in the end portions same as a
25 slot 10 shown in Fig. 23.

Slots 10 shown in Figs. 22A and 22B have circles with a radius r in their end portions, like the slots 10 explained with reference to Figs. 17A and 18A in the second embodiment. As in the second embodiment, it is possible with these shapes
 5 to enhance the emission of a microwave in circular portions 10a and uniformize a microwave radiated over the slot 10.

Also, the length of the slot 10 can be equivalently increased by increasing the radius r by adding a circle with the radius r to each end of the slot 10. Consequently, Q can
 10 be decreased without substantially setting the slot length to $\lambda g/2$. Furthermore, since the end portions of the slot 10 are circular, mechanical processing for forming the slot 10 can be easily and precisely performed.

In the third embodiment of the present invention as
 15 described above, with respect to a microwave emitted from the H plane, the slots 10 are formed in positions spaced apart by a predetermined distance d from the center (the central line C in Fig. 19B) of the waveguide 1. Consequently, a microwave can be radiated in phase from these slots 10.

20 Also, the shape of the slot 10 is curved, and this curved slot 10 is extended in a direction perpendicular to the directions of currents generated on the wall surface of the waveguide 1. This allows more efficient radiation of a microwave.

25 Furthermore, the width of the slot 10 is increased in its end portions. This makes it possible to enhance the

radiation of a microwave in the end portions of the slot 10 and uniformize the intensity of a microwave radiated in the entire area over the slot 10.

(Fourth Embodiment)

5 The fourth embodiment of the present invention will be described below. Note that the overall structure of an excimer laser oscillator according to this fourth embodiment is identical with the second embodiment, so a detailed description thereof will be omitted. Note also that in the
10 drawings for explaining the fourth embodiment the same reference numerals as in the second embodiment denote substantially the same parts, and a detailed description thereof will be omitted.

 According to the characteristic feature of the fourth
15 embodiment, in order to uniformize the radiation of a microwave, the opening shape of a slot 10 is a normal rectangular shape, and the internal shape of the wall of a waveguide 1 in which this slot 10 is formed is made different from the opening shape of the slot 10, thereby forming an
20 air-gap structure 215. As will be described later with reference to Fig. 24B, this air-gap structure 215 is an air gap formed in the wall surface of the waveguide 1 in which the slot 10 is formed.

 Figs. 25A and 25B show an example of the air-gap
25 structure 215. In this example, the entire region of the air-gap structure 215 is spaced apart by $\lambda g/4$ from the slot

10. Consequently, in this air-gap structure, the length of a space in a direction perpendicular to the slot 10 is $\lambda g/2$. Accordingly, it is possible to resonate a microwave in the air-gap structure 215 and increase the radiation efficiency.

Referring to Figs. 26A and 26B, the entire region of the air-gap structure 215 is spaced apart by $\lambda g/2$ from the slot 10. In this air-gap structure 215, the length of a space in a direction perpendicular to the slot 10 is also λg . So, it is possible to resonate microwaves in the air-gap structure 215 and improve the radiation efficiency.

Fig. 24A is a plan view showing the slot 10 and the air-gap structure 215 according to a modification of the fourth embodiment. Fig. 24B is a schematic sectional view showing a section taken along an alternate long and short dashed line I - I' shown in Fig. 24A.

As shown in Fig. 24A, the slot 10 according to the fourth embodiment has a rectangular shape, and its longitudinal direction is the same as the longitudinal direction of the waveguide 1.

The impedance changing air-gap structure 215 is so formed as to surround this rectangular slot 10. As shown in Fig. 24B, this air-gap structure 215 is formed in the inner wall of the waveguide 1 in which the slot 10 is formed. The air-gap structure 215 extends to a region indicated by the dotted line shown in Fig. 24A.

As shown in Fig. 24A, each end of the air-gap structure 215 is formed into a circle having a radius of $\lambda g/4$ from the end portion of the slot 10. In the central portion in the longitudinal direction of the slot 10, the distance from the end portion of the slot 10 is $\lambda g/4$ or less.

As shown in Fig. 24A, by changing the distance between air-gap end and the slot 10 in the long-axis direction of the slot 10, the emission characteristic of a microwave in the long-axis direction of the slot 10 can be changed.

This effect is due to the state in which resonance conditions do not hold in each portion of the slot 10 and to the intrinsic property of microwaves that the characteristics of a propagation path can be changed by changing the shape of a spatial gap. Impedance Z of a terminally short-circuited waveguide with length L and characteristic impedance Z_0 is

$$Z = jZ_0 \tan(2\pi \cdot L/\lambda g)$$

This indicates that a inductive element (a coil as a discrete element) and a capacitive element (a capacitor as a discrete element) having any arbitrary value can be formed by only changing L . Changing the half-width a in the slot line direction is equivalent, for an electromagnetic wave, to additionally changing the impedance of a slot (in an equivalent circuit, coils and capacitors having various values are connected in parallel with a slot). As a

consequence, the distribution of an electromagnetic wave emitted from the slot can be controlled.

By using this property, the radiation of a microwave in the longitudinal center of the slot 10 can be suppressed.
 5 So, the intensity of a microwave radiated over the slot 10 can be uniformized.

Figs. 27A and 27B show structures in which in order to increase the radiation efficiency of a microwave, the longitudinal length of the slot 10 is set to $\lambda g/2$. Fig. 27A
 10 shows a structure applied to the H plane. Fig. 27B shows a structure applied to the E plane. Since the length of the slot 10 is $\lambda g/2$, it is possible to resonate a microwave in the longitudinal direction of the slot 10 and improve the radiation efficiency of the microwave.

15 Fig. 28A shows a slot 10 having a tapered sectional shape which widens toward the inside of the waveguide 1. Since the taper which widens toward the lower portion of the slot 10 is formed, the spatial impedance moderately changes, so reflection hardly occurs. Consequently, a larger amount
 20 of a microwave can be introduced into the slot 10, and this increases the radiation efficiency of a microwave from the slot 10.

Fig. 28B shows an example in which a dielectric lens 216 is inserted into the tapered portion of the slot 10 shown
 25 in Fig. 28A. This dielectric lens 216 can concentrate a

microwave into the slot 10 and thereby increase the radiation efficiency of a microwave from the slot 10.

Also, as shown in Fig. 28C, a dielectric lens 217 can be placed immediately below the normal slot 10. This also
5 makes it possible to concentrate a microwave into the slot 10 and increase the radiation efficiency of a microwave from the slot 10.

In the fourth embodiment as described above, the air-gap structure 215 having a shape different from the
10 opening shape of the slot 10 is formed in the wall surface of the waveguide 1 in which the slot 10 is formed. This allows the impedance in the slot 10 to vary. Accordingly, the formation of this air-gap structure 215 realizes uniform microwave emission over the slot 10. Also, by setting the
15 air-gap region 215 to a predetermined size, a microwave can be resonated in this air-gap region 215, so the radiation characteristic of a microwave can be improved.

Furthermore, when the sectional shape of the slot 10 is tapered such that the slot 10 widens toward the inside
20 of the waveguide 1, a larger amount of a microwave can be introduced into the slot 10, so the radiation efficiency can be increased. The radiation efficiency of a microwave can also be increased by placing a dielectric lens in, or below, the slot 10.

25 As described above, the second to fourth embodiments can realize uniform plasma excitation over the length of each

individual slot. Therefore, it is possible to provide a laser oscillating apparatus capable of uniform laser emission with minimum energy loss, a high-performance exposure apparatus including this laser oscillating apparatus, and a high-quality device fabrication method using this exposure apparatus.

(Fifth Embodiment)

The fifth embodiment will be described next. The arrangement of a laser oscillating apparatus according to this fifth embodiment is identical with the second embodiment (Fig. 14), so its illustration and detailed description will be omitted.

Figs. 33A and 33B show a practical structure of a waveguide 1 according to the fifth embodiment. Fig. 33A is a schematic perspective view showing the waveguide 1. Fig. 33B is a plan view of the waveguide 1.

As shown in Fig. 33B, slots 10 are arranged in a line such that their longitudinal direction is consistent with the longitudinal direction of the waveguide 1. These slots 10 are arranged along the longitudinal direction of the waveguide 1, and each slot 10 extends in the longitudinal direction of the waveguide 1.

In this fifth embodiment, on the E plane of the waveguide 1, the slots 10 are formed in a line at a pitch of λ_g (λ_g : waveguide wavelength) in the longitudinal direction. Each slot 10 is formed in a position where the

emission characteristic of a microwave depending upon the slot 10 is contrary to the intensity distribution of a microwave propagating in the waveguide 1.

Fig. 29 shows practical positions of each slot 10. As shown in Fig. 29, in a comparative example, each slot 10 is formed in a position where a maximum value of the intensity distribution of a microwave (in this example shown in Fig. 29, the density distribution of an electric current flowing on the wall surface of the waveguide 1 is indicated as an index of the intensity distribution of a microwave) is in the center of the slot 10. As described above, when this is the case the intensity distribution due to the emission characteristic of a microwave depending upon the slot 10 is in substantially agreement with the intensity distribution of a microwave propagating in the waveguide 1. Hence, the intensity distribution of a microwave is as shown in Fig. 32A.

In contrast, in this embodiment shown in Fig. 29, the slots 10 are formed in positions equally shifted $\lambda g/4$ from the positions of the comparative example in each of which a maximum value of the intensity distribution of a microwave is in the center of the slot 10.

Accordingly, each slot 10 exists such that a minimum value of the intensity distribution of a microwave propagating in the waveguide 1 is positioned in substantially the center of the slot 10. Consequently, the intensity

distribution of a microwave propagating in the waveguide 1 is influenced by the intensity distribution due to the emission characteristic of a microwave depending upon the slot 10. As shown in Fig. 30, this increases the uniformity of the intensity distribution of a microwave emitted from each slot 10.

In this embodiment, the slots 10 are formed in a so-called E plane of the waveguide 1. However, the same argument holds even when a so-called H-plane antenna in which the slots 10 are formed in the H plane is used.

As shown in Fig. 31, this embodiment is also applicable to a structure in which the slots 10 are formed in a line at a pitch of $\lambda_g/2$ in the longitudinal direction. As in Fig. 29, the embodiment is shown in comparison with a comparative example. As shown in Fig. 30, the intensity distribution of a microwave emitted from each slot 10 actually increases.

More specifically, an E-plane emission antenna having L_a (width of the long end face) = 42 mm, L_b (width of the short end face) = 21 mm, and a waveguide resonator length (in the laser oscillation direction) of 220.8 mm was used to manufacture a 2.45-GHz microwave emission antenna having an aluminum alloy housing. A waveguide resonator was filled with alumina with a dielectric constant of 9.8. The wavelength in the waveguide resonator was 44.2 mm.

Accordingly, the slot pitch was also set to 44.2 mm and 22.1 mm for pitches of λg and $\lambda g/2$, respectively.

When a slot was formed in a position corresponding to an antinode (a portion where the intensity is a maximum) of the current density, sinusoidal irradiation as shown in Fig. 32A was obtained.

In contrast, when a slot was formed as it was shifted $\lambda g/4$, a standing-wave intensity distribution as shown in Fig. 32B was obtained.

Accordingly, the intensity distribution of a microwave emitted from the slot by this excitation is given as shown in Fig. 32C, indicating irradiation with higher uniformity than in Fig. 32A.

Note that this radiation characteristic is the characteristic of a slot alone in the absence of a plasma. Since a plasma is present in practice, more uniform excitation can be expected because there is propagation in a sheath portion and the like.

As described above, the excimer laser oscillator according to this embodiment employs a slot array structure and yet realizes plasma excitation uniform as a whole over the length of each individual slot and allows uniform laser emission with minimum energy loss.

In the fifth embodiment as described above, although a slot array structure is used, it is possible to realize plasma excitation uniform as a whole over the length of each

individual slot and emit uniform a laser beam with minimum energy loss.

(Sixth Embodiment)

The sixth embodiment will be described next. The arrangement of a laser oscillating apparatus according to the sixth embodiment is the same as the second embodiment (Fig. 14), and the structure of its waveguide is also identical with the fifth embodiment (Figs. 33A and 33B). So, their illustration and description will be omitted.

Fig. 34A shows a section near a laser tube 2 of a waveguide 1 in the sixth embodiment. That is, Fig. 34A shows a section in a direction perpendicular to the longitudinal direction of a slot 10.

As described earlier, a microwave radiated from the slot 10 excites a laser gas in the laser tube 2 to emit a plasma 311.

In this sixth embodiment, a mesh shield 313 is so formed as to surround a predetermined region over the slot 10. This mesh shield 313 is made of a metal mesh and has a function of preventing diffusion of a microwave emitted from the slot 10.

A laser gas flow path is formed over the slot 10. Since the mesh shield 313 is used, a laser gas flowing in the laser tube 2 can reach a portion above the slot 10 through this mesh shield 313.

Fig. 34B shows a structure in which a metal wall 315 is additionally formed on the mesh shield 313 shown in Fig. 34A. Since no laser gas flows upward from the slot 10, a microwave can be confined more reliably by the formation of this metal wall 315.

A microwave reduces its energy by $1/e^2$ ($\doteq 0.135$) times as it progresses by skin depth δ in a plasma in a cutoff mode. Therefore, when a plasma cuts off a microwave, a region where effective plasma excitation is possible is a space of about 3δ at the emission end if propagation in a sheath region is negligible. If a plasma exists in another region, this existing plasma is a plasma generated by diffusion.

Accordingly, when a plasma is confined in a space of about δ to 3δ from the emission end, a state in which a plasma is generated in the whole space is realized. In the structures shown in Figs. 34A and 34B, by setting the mesh shield 313 at a distance of δ to 3δ from the emission ends of the slot 10, a plasma can be excited in the whole area in the mesh shield 313.

When a microwave diffuses in the sheath region, the density at which energy is supplied to a plasma lowers. As a countermeasure for preventing this, microwave confinement by the mesh shield 313 is effective.

Letting λ_c be the cutoff wavelength of the basic structure of a shield and λ be the wavelength of a microwave

leaking from the sheath region, invasion length δs to the shield is given by

$$\delta s = \frac{1}{2\pi \sqrt{\frac{1}{\lambda c^2} - \frac{1}{\lambda^2}}}$$

A ratio p of the energy of a microwave entering the shield
5 to the energy of a microwave leaking outside the shield is

$$p = \exp\left(-\frac{2d}{\delta s}\right)$$

where d is the thickness of the shield. Accordingly, the
basic structure λc of the shield is determined, so when the
shield radiation ratio p is determined a minimum value of
10 d necessary for that can be calculated. Therefore, the lower
limit of a necessary shield thickness can be calculated. The
shield effect can be simply obtained by using a diameter of
below $1/4$ the wavelength in the waveguide.

As an example, when a mesh having a shield thickness
15 of 1 mm is used and energy leakage of an electromagnetic wave
to the outside is set to 1% or less, a necessary maximum
penetration length to the shield is 0.43 mm. When the basic
unit of a mesh is a rectangle and its peripheral length is
 a , $\lambda c = 2a$. When this is the case, a must be 1.4 mm or less.

20 The structure of this embodiment can prevent the
diffusion of a microwave propagating in the sheath in a plasma
generated by a microwave emitted from the slot 10. Therefore,
a plasma can be generated inside the mesh shield 313.

A plasma diffusing inside the mesh shield 313 acts as an internal axis of a coaxial waveguide, and consequently a portion where the plasma diffuses (the diffusion length of the plasma) operates as the coaxial waveguide. Hence, a
5 microwave switches to a TEM mode and easily propagates.

This propagation occurs in the sheath region where the penetration length to the plasma is not negligible with respect to the sheath thickness. Since loss due to the propagation is large, the propagation attenuates within a
10 short distance. However, this propagation sometimes still suffers a problem when confinement is performed.

That is, a microwave also propagates the diffusion length of the plasma in addition to the microwave cutoff length δ_s of the shield. Hence, the shield length must be
15 set to be equal to or larger than the cutoff length of a microwave alone + the diffusion length of a plasma.

Letting S be the surface area of a shield for performing confinement, α be the aperture ratio, P be the operating pressure, and k be the structure factor, conductance C (the
20 ease with which a gas flows) of a gas passing through the shield is, in the case of a viscous fluid, given by

$$C = k \frac{(\alpha S)^2 P}{d}$$

Accordingly, when the operating pressure and the shield structure are determined, the upper limit of the shield
25 thickness can be calculated.

The shield length and conductance necessary to cut off a microwave are contrary to each other with respect to α and d. Therefore, optimum values of these shield length and conductance can be defined from α and d.

5 The material of the shield desirably has a low resistivity to reduce loss of a microwave. Also, the thermal resistance of the material is desirably low because the shield is in contact with a plasma and hence is at high temperature. Furthermore, the material surface can be
10 subjected to the fluorine passivation process or covered with a fluorine-based compound.

 In the sixth embodiment as described above, the mesh shield 313 is so formed as to cover a portion above the slot
10. This prevents lateral diffusion of a plasma through the
15 sheath from the portion above the slot 10. The use of this mesh shield 313 can also realize more uniform discharge by avoiding electric field concentration in a plasma.

(Seventh Embodiment)

 The seventh embodiment of the present invention will
20 be described below with reference to the accompanying drawings.

 Fig. 35A is a perspective view showing a shielding structure for confining a plasma excited over a slot 10 into a predetermined region according to the seventh embodiment.
25 Note that the overall arrangement of an excimer laser oscillator according to the seventh embodiment is the same

is 1% or less. A maximum invasion length to the shield required in this case is 8.7 mm.

When the basic unit of the mesh is a rectangle and the length of its long side is a , $\lambda_c = 2a$. When this is the case,
 5 a must be 30 mm or less. Therefore, the spacing between the nozzles is 25 mm or less, i.e., a considerably wide margin can be set.

As an example, when the nozzle wall spacing is set to 20 mm, the leakage of 2.45-GHz microwave to the outside can
 10 be held at 1% or less even if a plasma diffuses by about 4.5 mm. This structure also has the advantage that a large conductance can be obtained. This is effective when a high-speed gas is to be supplied.

For example, the nozzle conductance of a nozzle having
 15 a 20 mm x 2 mm basic structure 20 mm long is 3.3 times as high as that of a mesh having a 1-mm thick square basic structure of 1 mm side for the same sectional area, although the thickness (length) is 20 times (assuming that the thicknesses of the mesh and the nozzle wall are 1 mm, the
 20 aperture ratios of the mesh and the nozzle are 25% and 91%, respectively). That is, the use of the nozzle structure extremely improves the ease with which gasses flow. In addition, turbulence often occurs in actual gas flows. To avoid this turbulence, the structure spacing is desirably
 25 as large as possible.

In the seventh embodiment as described above, a plurality of nozzles 314a each having an opening through which no a microwave can pass are arrayed to form the nozzle shield 314. Hence, a generated plasma can be confined in a predetermined region. Additionally, since a laser gas is allowed to flow through each nozzle 314a, few resistance is generated in the gas flow even though the shield structure is formed. This can minimize the production of pressure loss.

10 (Eighth Embodiment)

The eighth embodiment will be described below with reference to the accompanying drawings. Figs. 37A and 37B are schematic views showing the structures of magnetic shields according to the eighth embodiment. Figs. 38A and 38B and Fig. 39 are schematic views showing sections along a direction perpendicular to the longitudinal direction of a slot 10. Note that the overall arrangement of an excimer laser oscillator according to the eighth embodiment is identical with the sixth embodiment, so a detailed description thereof will be omitted. Note also that in the drawings for explaining the eighth embodiment, the same reference numerals as in the sixth embodiment denote substantially the same parts, and a detailed description thereof will be omitted.

25 In the eighth embodiment, a magnetic field is used to confine a plasma excited over the slot 10 into a predetermined

range. This magnetic field can be formed by using a solenoid as shown in Fig. 37A or by arranging general magnets as shown in Fig. 37B.

Fig. 37A shows an example using a solenoid 316 to form
 5 a magnetic field. As shown in Fig. 37, this solenoid 316 is placed such that the extending direction of the solenoid 316 is the same as the laser oscillation direction. That is, the longitudinal direction of a waveguide 1 and the slot 10 shown in Figs. 33A and 33B and the extending direction of the
 10 solenoid 316 are the same.

The field intensity is determined so that the Larmor period of an electron in the magnetic field is shorter than the collision period of an electron and an atom in a plasma (magnetic-field plasma condition). Letting B be a flux
 15 density, m be the mass of an electron, and e be elementary charge, the Larmor angular velocity of an electron is given by

$$\omega_{Larmor} = \frac{eB}{m}$$

Letting n be an atomic density, r be an atomic radius,
 20 T be an electron temperature, and k be a Boltzmann coefficient, the collision angular velocity of an electron and an atom is given by

$$\omega_{Collision} = 4\pi n r^2 \sqrt{\frac{2\pi k T}{m}}$$

From these equations, the flux density must be about 1 Torr or more when the operating pressure of an excimer laser and the like are taken into consideration.

When an intense magnetic field is applied by the solenoid 316, plasma electrons precess along the formed magnetic flux. Since the magnetic flux is formed in the same direction as the laser oscillation direction, the electrons do not easily diffuse in a direction perpendicular to the laser oscillation direction. This realizes plasma confinement. The same effect can be obtained when a magnetic field is formed using magnets 317 shown in Fig. 37B.

Fig. 38A is a schematic sectional view showing the arrangement of the solenoid 316 or the magnets 317 around the slot 10. To confine a plasma above the slot 10, it is desirable to place the magnets 317 in, e.g., four positions so as to surround a portion above the slot 10. In this manner, a plasma generated can be confined above the slot 10.

Fig. 38B shows an example in which a metal wall 315 is formed above the slot 10. This metal wall 315 prevents the upward diffusion of a plasma from the slot 10. Also, the solenoid 316 or the magnets 317 prevent the lateral diffusion of a plasma from the slot 10.

Fig. 39 shows a structure in which nozzle shields 314 are added to the structure shown in Fig. 38B. In this structure, the lateral diffusion of a plasma from the slot 10 can be prevented by the combined effect of the solenoid

Therefore, their illustration and description will be omitted.

Fig. 40 shows a section near a laser tube 2 of a waveguide 1 according to the ninth embodiment. This section
5 shown Fig. 40 is in a direction perpendicular to the longitudinal direction of a slot 10.

A microwave is radiated from the slot 10 formed in the waveguide 1 to generate a plasma above the slot 10. A sheath is formed between this plasma and the opening edges of the
10 slot 10. In this embodiment, the diameter (width) of the slot 10 is set to a value (10 to 100 μm) equal to or smaller than the sheath thickness in order to allow uniform propagation of a microwave. Therefore, it is possible to prevent the lateral propagation of a microwave from the slot 10 and
15 generate a plasma only in a portion above the slot 10. The dimension of the extension of a plasma over the slot 10 is preferably 1/10 or less of the laser beam diameter, since the influence on laser oscillation is little in this case.

In the ninth embodiment of the present invention as
20 described above, the width of the slot 10 is made smaller than the wavelength of a microwave. This prevents a plasma from diffusing laterally from over the slot 10 through a sheath.

(10th Embodiment)

25 The 10th embodiment of the present invention will be described below with reference to the accompanying drawings.

Fig. 43 shows an example in which when slits 411 are arranged in parallel, slits 411a in the end portions are made narrower than central slits 411.

When metal walls 415 are formed in the short-side direction of the opening edges of the slot 10 (slits 411) in order to prevent the diffusion of a plasma generated in the short-side direction of the slits 411, larger amounts of a plasma are generated in positions along these metal walls 415. This sometimes poses a problem of securing the uniformity of a plasma. As shown in Fig. 43, when the width in the short-side direction of the slits 411 in the end portions are made smaller than the width in the short-side direction of the central slits 411, the radiation intensity of a microwave radiated from these slits 411 can be decreased. Accordingly, a plasma generated over the slot 10 can be uniformized as a whole.

As shown in Fig. 44, it is also possible by decreasing the length of slits 411b in the end portions to suppress the generation of a plasma in the vicinities of the metal walls 415 and realize uniform plasma generation over the slot 10. Note that a similar effect can naturally be obtained by a structure equivalent, for microwaves, to the metal walls, i.e., by a structure capable of confining microwaves.

In the 10th embodiment as described above, the very narrow slits 411a are arranged in parallel. This makes it

possible to increase the emission efficiency of a microwave and uniformly generate a plasma over the slot 10.

In the ninth and 10th embodiments as described above, the diffusion of a plasma from over each individual slot to the outside of a predetermined range can be prevented. Accordingly, it is possible to provide a laser oscillating apparatus capable of uniform laser emission with minimum energy loss, a high-performance exposure apparatus including this laser oscillating apparatus, and a high-quality device fabrication method using this exposure apparatus. (11th Embodiment)

Fig. 45 is a schematic view showing the major components of an excimer laser oscillator according to the 11th embodiment of the present invention.

As shown in Fig. 45, this excimer laser oscillator comprises a laser tube 2, a pair of waveguides 1a and 1b, and a cooling vessel 7. The laser tube 2 emits a laser beam by resonating light emission caused by excitation of an excimer laser gas. The waveguides 1a and 1b excite the excimer laser gas in the laser tube 2 into a plasma. The cooling vessel 7 has cooling water inlet/outlet ports 9 for cooling the waveguides 1a and 1b.

The excimer laser gas as a material for generating an excimer laser beam is at least one inert gas selected from Kr, Ar, and Ne, or a gas mixture of at least one inert gas described above and F₂ gas. These gases can be appropriately

selected and used in accordance with the wavelength of interest. For example, Kr/Ne/F₂ is used when laser beam with a wavelength of 248 nm is to be generated; Ar/Ne/F₂ is used when a laser beam with a wavelength of 193 nm is to be
 5 generated; and Ne/F₂ is used when a laser beam with a wavelength of 157 nm is to be generated.

The laser tube 2 has laser gas inlet/output ports 8 through which the excimer laser gas is introduced into the tube, and reflecting structures 5 and 6 at the two end portions.
 10 These reflecting structures 5 and 6 equalize the phases of light by plasma discharge and generate a laser beam.

The waveguides 1a and 1b are means for supplying a microwave to the laser gas in a gas supply passage structure 11. A plurality of long and narrow gaps (slots) 10 are formed
 15 in the internal surface. When a microwave with a frequency of a few hundred MHz to several tens of GHz is introduced from the upper portions of the waveguides 1a and 1b shown in Fig. 1, this microwave propagates in the waveguides 1a and 1b and is emitted from the slots 10 to the outside of
 20 the waveguides 1a and 1b. The emitted microwave is introduced into the laser tube 2 through a window 15 formed in this laser tube 2. The microwave thus introduced excites the excimer laser gas in the laser tube 2, thereby generating an excimer laser beam by resonance.

25 In this 11th embodiment, as shown in Fig. 46, the formation surface of the slots 10 is the short end face of

each of the waveguides 1a and 1b, i.e., the E plane. Also, these slots 10 are formed in a line at equal intervals in the longitudinal direction.

In the 11th embodiment, the waveguides 1a and 1b as described above are so formed as to vertically sandwich the laser tube 2. These waveguides 1a and 1b are arranged such that the slots 10 corresponding to each other between the opposing slot formation surfaces are shifted a predetermined distance relative to each other (spatial shift; to be simply expressed as "shift" in the following tables). Furthermore, a phase adjusting shifter is used to shift the phases of microwaves supplied into the waveguides 1a and 1b relative to each other (phase shift; to be expressed as "shifter" in the following tables).

Fig. 47 is a graph showing the standing waves of microwaves in the waveguides 1a and 1b when the slots 10 are normally opposed (with no spatial shift and no phase shift), when the slots 10 are shifted a distance of $\lambda g/4$ (λg : waveguide wavelength), when the slots 10 are shifted a distance of $\lambda g/4$ and the phases are shifted by $\lambda g/4$, when the slots 10 are shifted a distance of $\lambda g/2$, and when the slots 10 are shifted a distance of $\lambda g/2$ and the phases are shifted by $\lambda g/2$.

Calculations for deriving the phase relationship between the standing waves in each case will be represented by the following equations.

Assuming that an incident wave passing through the phase adjusting shifter and shifted in phase by θ is

$$\exp(i(\omega t - \beta z + \theta - \pi/2))$$

a reflected wave is

5 $\exp(i(\omega t + \beta z + \theta + \pi/2 - 2\beta d))$

by taking account of a path length difference $2d$ produced because the waveguide end moves a distance d and phase inversion due to reflection at the waveguide end.

Accordingly, assuming there is no attenuation, the standing

10 wave generated is

$$2\exp(i(\omega t + \theta - \beta d))\sin(\beta z - \beta d)$$

for $\omega = 2\pi/T$ and $\beta = 2\pi/\lambda_g$.

When $d = 0$ and $\theta = 0$ (normal slot)

$$2\exp(i\omega t)\sin\beta z$$

15 When $d = \lambda_g/4$ and $\theta = 0$ ($\lambda_g/4$ shift)

$$2\exp[i\omega(t - T/4)]\sin\beta(z - \lambda_g/4)$$

When $d = \lambda_g/4$ and $\theta = \pi/2$ ($\lambda_g/4$ shift + $\lambda_g/4$ shifter)

$$2\exp(i\omega t)\sin\beta(z - \lambda_g/4)$$

When $d = \lambda_g/2$ and $\theta = 0$ ($\lambda_g/2$ shift)

20 $2\exp[i\omega(t - T/2)]\sin\beta(z - \lambda_g/2)$

When $d = \lambda_g/2$ and $\theta = \pi$ ($\lambda_g/2$ shift + $\lambda_g/2$ shifter)

$$2\exp(i\omega t)\sin\beta(z - \lambda_g/2)$$

From these relationships, the intensity-phase relationship between the standing waves is obtained.

25 When a waveguide in which the slots 10 are formed in the E plane at a pitch of $\lambda_g/2$ is used, microwaves emitted

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from adjacent slots are in opposite phases, so a space in which microwaves do not oscillate is formed between these slots. When a waveguide in which the slots 10 are formed in the E plane at a pitch of λg is used, microwaves emitted from adjacent slots are in phase with each other and hence do not cancel out each other. However, the uniformity in the slot longitudinal direction decreases because the slot interval is twice that when the pitch is $\lambda g/2$.

In this embodiment, a laser oscillating apparatus is so constructed that predetermined space shift and predetermined phase shift are performed by using a pair of waveguides having a pitch of λg , thereby complementing the microwave emission characteristics of the waveguides 1a and 1b described above.

A case in which the waveguides 1a and 1b are normally opposed with not space shift and no phase shift, a case in which the waveguides 1a and 1b are spatially shifted relative to each other, and a case in which both space shift and phase shift are performed will be described below for each of the pitches $\lambda g/2$ and λg of the slots 10 of the waveguides 1a and 1b.

First, an example of the normal opposing arrangement is shown in Table 2 (pitch $\lambda g/2$) and Table 3 (pitch λg). In Tables 2 and 3, the distribution in the laser resonance direction of a microwave in the upper waveguide 1a and the distribution of a microwave in the lower waveguide 1b are

indicated in upper and lower cells for each time. The + and
- signs indicate the polarity in an antinode of the standing
wave of a microwave. Hatched portions in each table indicate
the slots 10 actually formed in the upper and lower waveguides
5 1a and 1b. Note that hatched portions in Tables 4 to 11 (to
be described later) have the same meaning as in Tables 2 and
3.

Table 2

Normal slots (pitch $\lambda g/2$)

$\begin{array}{c} z \\ t \end{array}$	-3/2	-5/4	-1	-3/4	-1/2	-1/4	0	1/4	1/2
+0	-	0	+	0	-	0	+	None	None
	-	0	+	0	-	0	+	None	None
+1/4	0	0	0	0	0	0	0	None	None
	0	0	0	0	0	0	0	None	None
+1/2	+	0	-	0	+	0	-	None	None
	+	0	-	0	+	0	-	None	None
+3/4	0	0	0	0	0	0	0	None	None
	0	0	0	0	0	0	0	None	None

Table 3

Normal slots (pitch $\lambda g/2$)

$\begin{array}{c} z \\ t \end{array}$	-3/2	-5/4	-1	-3/4	-1/2	-1/4	0	1/4	1/2
+0	-	0	+	0	-	0	+	None	None
	-	0	+	0	-	0	+	None	None
+1/4	0	0	0	0	0	0	0	None	None
	0	0	0	0	0	0	0	None	None
+1/2	+	0	-	0	+	0	-	None	None
	+	0	-	0	+	0	-	None	None
+3/4	0	0	0	0	0	0	0	None	None
	0	0	0	0	0	0	0	None	None

A case in which $\lambda g/4$ space shift is performed at a pitch of $\lambda g/2$ is shown in Table 4, and a case in which $\lambda g/4$ space shift and $\lambda g/4$ phase shift are performed at the same pitch is shown in Table 5. Fig. 49A shows these cases (Fig. 49A is an enlarged view of the waveguides 1a and 1b in Fig. 48). Also, a case in which $\lambda g/2$ space shift is performed is shown in Table 6, and a case in which $\lambda g/2$ space shift and $\lambda g/2$ phase shift are performed is shown in Table 7.

Table 4

$\lambda g/4$ shift slots

$\begin{array}{c} z \\ t \end{array}$	-3/2	-5/4	-1	-3/4	-1/2	-1/4	0	1/4	1/2
+0	0	0	0	0	0	0	0	0	None
	-	0	+	0	-	0	+	None	None
+1/4	0	+	0	+	0	-	0	+	None
	0	0	0	0	0	0	0	None	None
+1/2	0	0	0	0	0	0	0	0	None
	+	0	-	0	+	0	-	None	None
+3/4	0	+	0	-	0	+	0	-	None
	0	0	0	0	0	0	0	None	None

5

Table 5

$\lambda g/4$ shift + $\lambda g/4$ shifter slots

$z \backslash t$	-3/2	-5/4	-1	-3/4	-1/2	-1/4	0	1/4	1/2
+0	0	-	0	+	0	-	0	+	None
	-	0	+	0	-	0	-	None	None
+1/4	0	0	0	0	0	0	0	0	None
	0	0	0	0	0	0	0	None	None
+1/2	0	+	0	-	0	+	0	-	None
	+	0	-	0	+	0	-	None	None
+3/4	0	0	0	0	0	0	0	0	None
	0	0	0	0	0	0	0	None	None

Table 6

$\lambda g/2$ shift slots

$\begin{matrix} z \\ t \end{matrix}$	-3/2	-5/4	-1	-3/4	-1/2	-1/4	0	1/4	1/2
+0	-	0	+	0	-	0	+	0	-
	-	0	+	0	-	0	+	None	None
+1/4	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	None	None
+1/2	+	0	-	0	+	0	-	0	+
	+	0	-	0	+	0	-	None	None
+3/4	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	None	None

Table 7

$\lambda g/2$ shift + $\lambda g/2$ shifter slots

$\begin{matrix} z \\ t \end{matrix}$	-3/2	-5/4	-1	-3/4	-1/2	-1/4	0	1/4	1/2
+0	+	0	-	0	+	0	-	0	+
	-	0	+	0	-	0	+	None	None
+1/4	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	None	None
+1/2	-	0	+	0	-	0	+	0	-
	+	0	-	0	+	0	-	None	None
+3/4	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	None	None

When $\lambda g/4$ space shift is performed, the phase relationship between the upper and lower slots 10 is shifted by $\pi/2$, the plasma excitation has a double period. When $\lambda g/2$ space shift is performed, the plasma excitation has only
5 one period, so the problem of the double period is avoided. However, sufficient intensity is usually difficult to obtain owing to the aforementioned properties of the pitch $\lambda g/2$ that adjacent slots 10 in the waveguides 1a and 1b have opposite phases.

10 A case in which $\lambda g/4$ space shift is performed at a pitch of λg is shown in Table 8, and a case in which $\lambda g/4$ space shift and $\lambda g/4$ phase shift are performed at the same pitch is shown in Table 9. Also, a case in which $\lambda g/2$ space shift is performed is shown in Table 10, and a case
15 in which $\lambda g/2$ space shift and $\lambda g/2$ phase shift are performed is shown in Table 11. Fig. 49B shows these cases (Fig. 49B is an enlarged view of the waveguides 1a and 1b in Fig. 48).

Table 8

$\lambda g/4$ shift slots

$\begin{matrix} z \\ t \end{matrix}$	-3/2	-5/4	-1	-3/4	-1/2	-1/4	0	1/4	1/2
+0	0	0	0	0	0	0	0	0	None
	-	0	+	0	-	0	+	None	None
+1/4	0	-	0	+	0	-	0	+	None
	0	0	0	0	0	0	0	None	None
+1/2	0	0	0	0	0	0	0	0	None
	+	0	-	0	+	0	-	None	None
+3/4	0	+	0	-	0	+	0	-	None
	0	0	0	0	0	0	0	None	None

Table 9

$\lambda g/4$ shift slots + $\lambda g/4$ shifter slots

$\begin{array}{c} z \\ \backslash \\ t \end{array}$	-3/2	-5/4	-1	-3/4	-1/2	-1/4	0	1/4	1/2
+0	0	-	0	+	0	-	0	+	None
	-	0	+	0	-	0	+	None	None
+1/4	0	0	0	0	0	0	0	0	None
	0	0	0	0	0	0	0	None	None
+1/2	0	+	0	-	0	+	0	-	None
	+	0	-	0	+	0	-	None	None
+3/4	0	0	0	0	0	0	0	0	None
	0	0	0	0	0	0	0	None	None

Table 11

$\lambda g/2$ shift slots + $\lambda g/2$ shifter slots

z t	-3/2	-5/4	-1	-3/4	-1/2	-1/4	0	1/4	1/2
+0	+	0	-	0	+	0	-	0	+
	-	0	+	0	-	0	+	None	None
+1/4	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	None	None
+1/2	-	0	+	0	-	0	+	0	-
	+	0	-	0	+	0	-	None	None
+3/4	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	None	None

When $\lambda g/4$ space shift is performed, the plasma excitation has a double period as described previously. However, when the polarity of one of upper and lower corresponding slots 10 is + or - (when plasma is excited), the other polarity is 0 (no plasma is excited). Additionally, adjacent slots 10 in the waveguides 1a and 1b are in phase with each other. Accordingly, although there is a slight problem in the uniformity of light emission over the length of the waveguides 1a and 1b, emission uniformity to some extent can be expected.

Also, when $\lambda g/4$ space shift and $\lambda g/4$ phase shift are performed, the problem of the double period of light emission is avoided as described above. Additionally, adjacent slots 10 in the waveguides 1a and 1b are in phase with each other. Accordingly, although there is a slight problem in the uniformity of light emission over the length of the waveguides 1a and 1b, emission uniformity to some extent can be expected.

When $\lambda g/2$ space shift is performed, adjacent slots 10 in the waveguides 1a and 1b are in phase with each other. However, the upper and lower slots 10 have alternate polarities over the length of the waveguides 1a and 1b, so these upper and lower slots 10 may cancel out each other.

When $\lambda g/2$ space shift and $\lambda g/2$ phase shift are performed, the problem of the double period of plasma excitation is avoided as described above. Additionally, not

only adjacent slots 10 in the waveguides 1a and 1b are in phase with each other, but also the upper and lower slots 10 are in phase with each other over the length of the waveguides 1a and 1b. Accordingly, all the upper and lower
 5 slots 10 uniformly emit a microwave in phase with each other. This realizes uniform plasma discharge over the length of the laser tube 2.

As described above, plasma discharge can be uniformized most optimally when $\lambda g/2$ space shift and $\lambda g/2$
 10 phase shift are performed at the pitch λg . Note that as described above, even in other cases, the uniformization of plasma discharge can be suitably realized depending on, e.g., the shape of the waveguide or the properties of a microwave.
 (Modification)

15 A modification of the 11th embodiment will be described below. The same reference numerals as in the embodiment denote the same parts, and a detailed description thereof will be omitted.

In this embodiment, as shown in Fig. 50, the formation
 20 surface of the slots 10 is the lone end face, i.e., the H plane, of each of the waveguides 1a and 1b. These slots 10 are formed at equal intervals d on the right- and left-hand sides at a predetermined pitch (in this modification, a pitch of $\lambda g/2$) along the central line in the longitudinal direction
 25 of the H plane.

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In this modification, as shown in Fig. 51, the pair of waveguides 1a and 1b are so formed as to vertically sandwich the laser tube 2 such that the corresponding slots 10 are positioned on the right- and left-hand sides between the
5 opposing formation surfaces. Basically, this structure does not require any space shift or phase shift as in the above embodiment.

The arrows in Fig. 51 indicate electric currents flowing in the waveguide walls. A microwave exists as a
10 standing wave in a propagation space defined by the distance in the longitudinal direction of the waveguides 1a and 1b. Owing to this standing wave, the currents in the waveguide walls also take the form of a standing wave. However, the form of the standing wave of a microwave is three-dimensional
15 and complicated. So, it is convenient to consider only the electric field of a transient progressive wave (or reflected wave).

That is, between the upper and lower corresponding slots 10, the directions of currents flowing in the
20 waveguides indicated by the arrows in Fig. 51 are the same (the direction indicated by an arrow 100). Also, the current directions are the same between adjacent upper and lower, right and left slots 10 of the waveguides 1a and 1b. Accordingly, microwaves emitted from the slots 10 are in
25 phase with each other, so their standing waves do not cancel out each other.

In this modification, therefore, with a simpler arrangement than that of the above embodiment, microwaves are uniformly radiated in phase with each other from the upper and lower slots 10. This realizes uniform plasma discharge
5 over the length of the laser tube 2.

As described above, the excimer laser oscillators of the 11th embodiment and its modification employ a slot array structure and yet realize uniform electromagnetic wave radiation over the length of a laser tube and allow uniform
10 laser emission with minimum energy loss.

Note that the 11th embodiment is generally based on the assumption that the three-dimensional circuit from the waveguide resonator end to the microwave power supply is symmetrical in terms of a microwave. If this
15 three-dimensional circuit is asymmetrical, phase shift or the like for compensating for this asymmetry is naturally required.

In the 11th embodiment as described above, although a slot array structure is used, it is possible to realize
20 uniform electromagnetic wave radiation over the length of a laser tube and allow uniform laser emission with minimum energy loss.

(12th Embodiment)

The 12th embodiment will be described below. In this
25 12th embodiment, an exposure apparatus (stepper) having the excimer laser oscillator described in any of the first to

placed near the position of secondary sources formed by the optical integrator 123 and can be switched to an arbitrary aperture value by a switching means (not shown). The condenser lens 125 condenses the illuminating light passing
 5 through the stop member 124. The blind 127 is constructed of, e.g., four variable blades and placed on the conjugate plane of the reticle 101 to determine an arbitrary illuminating range on the surface of the reticle 101. The image forming lens 128 projects the illuminating light formed
 10 into a predetermined shape by the blind 127 onto the surface of the reticle 101. The reflecting mirror 29 reflects the illuminating light from the image forming lens 128 toward the reticle 101.

An operation of projecting the pattern on the reticle
 15 101 onto the surface of the wafer 102 in a reduced scale by using the stepper constructed as above will be described below.

First, the illuminating light emitted from the light source 121 is converted into a predetermined shape by the
 20 beam shape converting means 122 and directed to the optical integrator 123. Consequently, a plurality of secondary sources are formed near the exit surface of the optical integrator 123. Illuminating light from these secondary sources is condensed by the condenser lens 125 via the stop
 25 member 124 and formed into a predetermined shape by the blind 127. After that, the illuminating light is reflected by the

reflecting mirror 129 via the image forming lens 128 and enters the reticle 101. Subsequently, the illuminating light enters the projecting optical system 122 through the pattern of the reticle 101. As the illuminating light passes
5 through the projecting optical system, the pattern is reduced into predetermined dimensions and projected onto the surface of the wafer 102 to expose it.

The stepper of this embodiment uses the excimer laser oscillator of the first embodiment as a laser source.
10 Therefore, a high-output and uniform excimer laser beam can be emitted for a relatively long time period. This allows rapid exposure of the wafer 102 with an accurate exposure amount.

Next, a semiconductor device fabrication method using
15 the projecting exposure apparatus explained with reference to Fig. 52 will be described below.

Fig. 53 shows the flow of fabrication steps of semiconductor devices (e.g., semiconductor chips such as ICs and LSIs, liquid crystal panels, or CCDs). First, in step
20 1 (circuit design), circuits of semiconductor devices are designed. In step 2 (mask formation), a mask having the designed circuit patterns is formed. In step 3 (wafer fabrication), wafers are fabricated by using materials such as silicon. Step 4 (wafer process) is called a pre-process
25 in which actual circuits are formed on the wafers by the photolithography technique by using the mask and wafers

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prepared as above. Step 5 (assembly) is called a post-process in which semiconductor chips are formed from the wafers formed in step 4. This process includes steps such as an assembly step (dicing and bonding) and a packaging step (chip encapsulation). In step 6 (testing), tests such as an operation test and a durability test are conducted on the semiconductor devices fabricated in step 5. The semiconductor devices are completed through these steps and shipped (step 7).

10 Fig. 54 shows a detailed flow of the wafer process described above. In step 11 (oxidation), the surfaces of the wafers are oxidized. In step 12 (CVD), conductive films and insulating films are formed on the wafer surfaces by using vapor phase reaction. In step 13 (PVD), conductive films and
15 insulating films are formed on the wafers by sputtering or vapor deposition. In step 14 (ion implantation), ions are implanted into the wafers. In step 15 (resist processing), the wafers are coated with a photosensitive agent. In step 16 (exposure), the projecting exposure apparatus explained
20 above is used to expose the wafers to the circuit patterns of the mask. In step 17 (development), the exposed wafers are developed. In step 18 (etching), portions except for the developed resist image are etched away. In step 19 (resist removal), the unnecessary resist after the etching is removed.
25 Multiple circuit patterns are formed on the wafers by repeating these steps.

This fabrication method can easily and reliably fabricate, with high yield, highly integrated semiconductor devices which are conventionally difficult to fabricate.

As many apparently widely different embodiments of the
5 present invention can be made without departing from the spirit and scope thereof, it is to be understood that the invention is not limited to the specific embodiments thereof except as defined in the appended claims.

electromagnetic waves introduced from said plurality of slots can overlap with each other.

5. The apparatus according to claim 4, wherein the distance from said slots to said laser tube wall is an integral multiple of the half-wave length of an electromagnetic wave introduced from said waveguide.

6. The apparatus according to claim 4, wherein an electromagnetic wave introduced from said waveguide is a microwave.

10 7. The apparatus according to claim 4, wherein said passage is made from a conductor.

8. The apparatus according to claim 7, wherein in at least a portion where said passage is in contact with said laser tube, said passage forms an air gap having an opening with a predetermined width over the length of said laser tube.

9. The apparatus according to claim 8, wherein said air gap is filled with a dielectric member.

10. The apparatus according to claim 9, wherein said dielectric member comprises a plurality of dielectric members having different dielectric constants.

11. The apparatus according to claim 8, wherein the width of said air gap is an integral multiple of the half-wave length of an electromagnetic wave introduced from said waveguide.

12. The apparatus according to claim 8, wherein only a distal end portion of said air gap is narrowed, and the opening has the shape of a slit over the length of said laser tube.

13. The apparatus according to claim 8, wherein said air gap has wide portions wider than the other portion in the vicinities of distal end portions.

14. The apparatus according to claim 13, wherein the width
5 of said wide portion is substantially equal to one of the wavelength and the half-wave length of an electromagnetic wave introduced from said waveguide.

15. The apparatus according to claim 13, wherein the width
10 of said wide portion changes along a longitudinal direction of said air gap on the basis of an intensity distribution of electromagnetic waves emitted from said slots.

16. The apparatus according to claim 4, wherein dielectric lenses each having a curved shape corresponding to said slot are formed in said passage in at least a portion above said
15 plurality of slots.

17. The apparatus according to claim 4, wherein said waveguide is filled with a dielectric member.

18. The apparatus according to claim 4, wherein said laser gas is one of at least one inert gas selected from the group
20 consisting of Kr, Ar, He and Ne, and a gas mixture of said inert gas and F_2 gas.

19. The apparatus according to claim 1, wherein said uniformizing means is formed such that the width of longitudinal end portions of said slot is made larger than
25 the width of a central portion thereof.

end portions of said slot within a range from said end portions to a distance of $\lambda g/4$ (λg is the waveguide wavelength of said electromagnetic wave).

27. The apparatus according to claim 25, wherein said
5 air-gap structure includes an air-gap portion formed near end portions of said slot within a range from said end portions to a distance of $\lambda g/2$ (λg is the waveguide wavelength of said electromagnetic wave).

28. The apparatus according to claim 25, wherein an air-gap
10 portion of said air-gap structure in a central portion of said slot is made smaller than an air-gap portion near end portions of said slot.

29. The apparatus according to claim 25, wherein in a
15 direction perpendicular to a longitudinal direction of said slot, said air-gap structure is formed with a width equal to an integral multiple of $\lambda g/2$ (λg is the waveguide wavelength of said electromagnetic wave).

30. The apparatus according to claim 25, wherein said laser
20 gas is one of at least one inert gas selected from the group consisting of Kr, Ar, He and Ne, and a gas mixture of said inert gas and F_2 gas.

31. The apparatus according to claim 1, wherein said
25 uniformizing means is formed such that each of said plurality of slots comprises collecting means for efficiently guiding said electromagnetic wave to said slot.

distribution of an electromagnetic wave propagating in said waveguide is in substantially the center of said slot.

39. The apparatus according to claim 38, wherein said slots are formed in a line at a pitch equal to one of the wavelength and the half-wave length of an electromagnetic wave in said waveguide.

40. The apparatus according to claim 37, wherein an electromagnetic wave introduced from said waveguide is a microwave.

41. The apparatus according to claim 37, wherein said laser gas is one of at least one inert gas selected from the group consisting of Kr, Ar, He and Ne, and a gas mixture of said inert gas and F₂ gas.

42. The apparatus according to claim 1, wherein said
15 uniformizing means comprises a shielding structure against
said electromagnetic wave in said laser tube in order to
prevent said plasma excited above said slots from diffusing
from a predetermined region.

43. The apparatus according to claim 42, wherein said
20 shielding structure is formed to prevent diffusion of said
electromagnetic wave in a direction perpendicular to a
longitudinal direction of said slots.

44. The apparatus according to claim 42, wherein said
shielding structure comprises a metal wall spaced apart from
25 said slots by a predetermined distance.

53. The apparatus according to claim 1, wherein said uniformizing means is formed such that each of said slots comprises a plurality of rows of slits, and the width of each slit is made smaller than the thickness of a sheath serving
5 as a passage of said electromagnetic wave.

54. The apparatus according to claim 53, wherein the width of slits in end rows is smaller than the width of slits in rows near the center.

55. The apparatus according to claim 54, wherein a
10 shielding structure for suppressing diffusion of said plasma is formed laterally at an opening edge of said slot facing said laser tube.

56. The apparatus according to claim 53, wherein the length of slits in end rows is smaller than the length of slits in
15 rows near the center.

57. The apparatus according to claim 53, wherein said laser gas is one of at least one inert gas selected from the group consisting of Kr, Ar, He and Ne, and a gas mixture of said inert gas and F_2 gas.

58. The apparatus according to claim 1, wherein said uniformizing means is formed such that a pair of waveguides are formed to sandwich said laser tube such that formation surfaces of said slots oppose each other, identical
25 electromagnetic waves are supplied to said pair of waveguides to excite a laser gas in two opposite directions in said laser tube, and said pair of waveguides are constructed such that

intensity distributions of electromagnetic waves introduced therefrom are shifted from each other.

59. The apparatus according to claim 58, wherein the formation surfaces of said slots are short end faces of said waveguides, and said slots are formed in a line at equal intervals in a longitudinal direction of said slots.

60. The apparatus according to claim 59, wherein said waveguides are arranged such that slots corresponding to each other between the opposing formation surfaces are shifted relative to each other by a predetermined distance.

61. The apparatus according to claim 60, wherein said slots are formed at a pitch equal to half of a wavelength in said waveguides, and said predetermined distance is $1/4$ of said wavelength.

62. The apparatus according to claim 60, wherein said slots are formed at a pitch equal to one wavelength in said waveguides, and said predetermined distance is half of said wavelength.

63. The apparatus according to claim 60, further comprising phase adjusting means for shifting phases of electromagnetic waves supplied into said waveguides relative to each other.

64. The apparatus according to claim 59, wherein each of said waveguides comprises tuning means for tuning an electromagnetic wave.

65. The apparatus according to claim 58, wherein an electromagnetic wave introduced from said waveguide is a microwave.

66. The apparatus according to claim 58, wherein said laser
5 gas is one of at least one inert gas selected from the group
consisting of Kr, Ar, He and Ne, and a gas mixture of said
inert gas and F₂ gas.

67. An exposure apparatus comprising:

the laser oscillating apparatus according to claim 4
10 as a light source for emitting illuminating light;

a first optical system for irradiating a reticle on which a predetermined pattern is formed with the illuminating light from said laser oscillating apparatus; and

a second optical system for irradiating a surface to
15 be irradiated with the illuminating light passing through
said reticle,

wherein said surface to be irradiated is exposed by projecting the predetermined pattern of said reticle.

68. An exposure apparatus comprising:

20 the laser oscillating apparatus according to claim 19
as a light source for emitting illuminating light;

a first optical system for irradiating a reticle on which a predetermined pattern is formed with the illuminating light from said laser oscillating apparatus; and

a second optical system for irradiating a surface to be irradiated with the illuminating light passing through said reticle,

wherein said surface to be irradiated is exposed by projecting the predetermined pattern of said reticle.

69. An exposure apparatus comprising:

the laser oscillating apparatus according to claim 22 as a light source for emitting illuminating light;

a first optical system for irradiating a reticle on which a predetermined pattern is formed with the illuminating light from said laser oscillating apparatus; and

a second optical system for irradiating a surface to be irradiated with the illuminating light passing through said reticle,

wherein said surface to be irradiated is exposed by projecting the predetermined pattern of said reticle.

70. An exposure apparatus comprising:

the laser oscillating apparatus according to claim 25 as a light source for emitting illuminating light;

a first optical system for irradiating a reticle on which a predetermined pattern is formed with the illuminating light from said laser oscillating apparatus; and

a second optical system for irradiating a surface to be irradiated with the illuminating light passing through said reticle,

wherein said surface to be irradiated is exposed by projecting the predetermined pattern of said reticle.

71. An exposure apparatus comprising:

the laser oscillating apparatus according to claim 31
5 as a light source for emitting illuminating light;

a first optical system for irradiating a reticle on which a predetermined pattern is formed with the illuminating light from said laser oscillating apparatus; and

a second optical system for irradiating a surface to
10 be irradiated with the illuminating light passing through said reticle,

wherein said surface to be irradiated is exposed by projecting the predetermined pattern of said reticle.

72. An exposure apparatus comprising:

15 the laser oscillating apparatus according to claim 35 as a light source for emitting illuminating light;

a first optical system for irradiating a reticle on which a predetermined pattern is formed with the illuminating light from said laser oscillating apparatus; and

20 a second optical system for irradiating a surface to be irradiated with the illuminating light passing through said reticle,

wherein said surface to be irradiated is exposed by projecting the predetermined pattern of said reticle.

25 73. An exposure apparatus comprising:

a first optical system for irradiating a reticle on which a predetermined pattern is formed with the illuminating light from said laser oscillating apparatus; and

a second optical system for irradiating a surface to
5 be irradiated with the illuminating light passing through said reticle,

wherein said surface to be irradiated is exposed by projecting the predetermined pattern of said reticle.

76. An exposure apparatus comprising:

10 the laser oscillating apparatus according to claim 53 as a light source for emitting illuminating light;

a first optical system for irradiating a reticle on which a predetermined pattern is formed with the illuminating light from said laser oscillating apparatus; and

15 a second optical system for irradiating a surface to be irradiated with the illuminating light passing through said reticle,

wherein said surface to be irradiated is exposed by projecting the predetermined pattern of said reticle.

20 77. An exposure apparatus comprising:

the laser oscillating apparatus according to claim 58 as a light source for emitting illuminating light;

a first optical system for irradiating a reticle on which a predetermined pattern is formed with the illuminating

25 light from said laser oscillating apparatus; and

a second optical system for irradiating a surface to be irradiated with the illuminating light passing through said reticle,

wherein said surface to be irradiated is exposed by projecting the predetermined pattern of said reticle.

78. A device fabrication method comprising the steps of:
coating a surface to be irradiated with a photosensitive material;

exposing said surface to be irradiated coated with said photosensitive material to a predetermined pattern by using the exposure apparatus according to claim 67; and

developing said photosensitive material exposed to the predetermined pattern.

79. The method according to claim 78, wherein said surface to be irradiated is a wafer surface, and a semiconductor device is formed on said wafer surface.

80. A device fabrication method comprising the steps of:
coating a surface to be irradiated with a photosensitive material;

exposing said surface to be irradiated coated with said photosensitive material to a predetermined pattern by using the exposure apparatus according to claim 68; and

developing said photosensitive material exposed to the predetermined pattern.

coating a surface to be irradiated with a
photosensitive material;

exposing said surface to be irradiated coated with said
photosensitive material to a predetermined pattern by using
5 the exposure apparatus according to claim 71; and

developing said photosensitive material exposed to the
predetermined pattern.

87. The method according to claim 86, wherein said surface
to be irradiated is a wafer surface, and a semiconductor
10 device is formed on said wafer surface.

88. A device fabrication method comprising the steps of:

coating a surface to be irradiated with a
photosensitive material;

exposing said surface to be irradiated coated with said
15 photosensitive material to a predetermined pattern by using
the exposure apparatus according to claim 72; and

developing said photosensitive material exposed to the
predetermined pattern.

89. The method according to claim 88, wherein said surface
20 to be irradiated is a wafer surface, and a semiconductor
device is formed on said wafer surface.

90. A device fabrication method comprising the steps of:

coating a surface to be irradiated with a
photosensitive material;

exposing said surface to be irradiated coated with said photosensitive material to a predetermined pattern by using the exposure apparatus according to claim 73; and

developing said photosensitive material exposed to the
5 predetermined pattern.

91. The method according to claim 90, wherein said surface to be irradiated is a wafer surface, and a semiconductor device is formed on said wafer surface.

92. A device fabrication method comprising the steps of:
10 coating a surface to be irradiated with a photosensitive material;

exposing said surface to be irradiated coated with said photosensitive material to a predetermined pattern by using the exposure apparatus according to claim 74; and

15 developing said photosensitive material exposed to the predetermined pattern.

93. The method according to claim 92, wherein said surface to be irradiated is a wafer surface, and a semiconductor device is formed on said wafer surface.

20 94. A device fabrication method comprising the steps of:
coating a surface to be irradiated with a photosensitive material;

exposing said surface to be irradiated coated with said photosensitive material to a predetermined pattern by using
25 the exposure apparatus according to claim 75; and

developing said photosensitive material exposed to the predetermined pattern.

95. The method according to claim 94, wherein said surface to be irradiated is a wafer surface, and a semiconductor device is formed on said wafer surface.

96. A device fabrication method comprising the steps of:
coating a surface to be irradiated with a photosensitive material;

exposing said surface to be irradiated coated with said photosensitive material to a predetermined pattern by using the exposure apparatus according to claim 76; and

developing said photosensitive material exposed to the predetermined pattern.

97. The method according to claim 96, wherein said surface to be irradiated is a wafer surface, and a semiconductor device is formed on said wafer surface.

98. A device fabrication method comprising the steps of:
coating a surface to be irradiated with a photosensitive material;

exposing said surface to be irradiated coated with said photosensitive material to a predetermined pattern by using the exposure apparatus according to claim 77; and

developing said photosensitive material exposed to the predetermined pattern.

99. The method according to claim 98, wherein said

surface to be irradiated is a wafer surface, and a semiconductor device is formed on said wafer surface.

100. An exposure apparatus comprising:

the laser oscillating apparatus according to claim 1
5 as a light source for emitting illuminating light;

a first optical system for irradiating a reticle on which a predetermined pattern is formed with the illuminating light from said laser oscillating apparatus; and

a second optical system for irradiating a surface to
10 be irradiated with the illuminating light passing through said reticle,

wherein said surface to be irradiated is exposed by projecting the predetermined pattern of said reticle.

101. An exposure apparatus comprising:

the laser oscillating apparatus according to claim 2
15 as a light source for emitting illuminating light;

a first optical system for irradiating a reticle on which a predetermined pattern is formed with the illuminating light from said laser oscillating apparatus; and

a second optical system for irradiating a surface to
20 be irradiated with the illuminating light passing through said reticle,

wherein said surface to be irradiated is exposed by projecting the predetermined pattern of said reticle.

25 102. An exposure apparatus comprising:

the laser oscillating apparatus according to claim 3
as a light source for emitting illuminating light;

a first optical system for irradiating a reticle on which a predetermined pattern is formed with the illuminating light from said laser oscillating apparatus; and

a second optical system for irradiating a surface to be irradiated with the illuminating light passing through said reticle,

wherein said surface to be irradiated is exposed by
10 projecting the predetermined pattern of said reticle.

103. A device fabrication method comprising the steps of:

coating a surface to be irradiated with a
photosensitive material;

exposing said surface to be irradiated coated with said
15 photosensitive material to a predetermined pattern by using
the exposure apparatus according to claim 100; and

developing said photosensitive material exposed to the predetermined pattern.

104. The method according to claim 103, wherein said surface
20 to be irradiated is a wafer surface, and a semiconductor
device is formed on said wafer surface.

105. A device fabrication method comprising the steps of:

coating a surface to be irradiated with a
photosensitive material;

exposing said surface to be irradiated coated with said
photosensitive material to a predetermined pattern by using
the exposure apparatus according to claim 101; and

developing said photosensitive material exposed to the
5 predetermined pattern.

106. The method according to claim 105, wherein said surface
to be irradiated is a wafer surface, and a semiconductor
device is formed on said wafer surface.

107. A device fabrication method comprising the steps of:
10 coating a surface to be irradiated with a
photosensitive material;

exposing said surface to be irradiated coated with said
photosensitive material to a predetermined pattern by using
the exposure apparatus according to claim 102; and

15 developing said photosensitive material exposed to the
predetermined pattern.

108. The method according to claim 78, wherein said surface
to be irradiated is a wafer surface, and a semiconductor
device is formed on said wafer surface.

20

ABSTRACT OF THE DISCLOSURE

In a laser oscillating apparatus for exciting a laser gas in a laser tube by introducing an electromagnetic wave from a waveguide into the laser tube through a plurality of slots formed in a waveguide wall, and generating a laser beam by resonating light emitted from the laser gas, the slots are formed in a line such that their longitudinal direction is consistent with the longitudinal direction of the waveguide, and a metal wall is so formed as to surround these slots. This metal wall forms a gap as a microwave passage from the slots to a window in the laser tube wall, thereby spacing the laser tube wall apart from the slots by a predetermined distance.

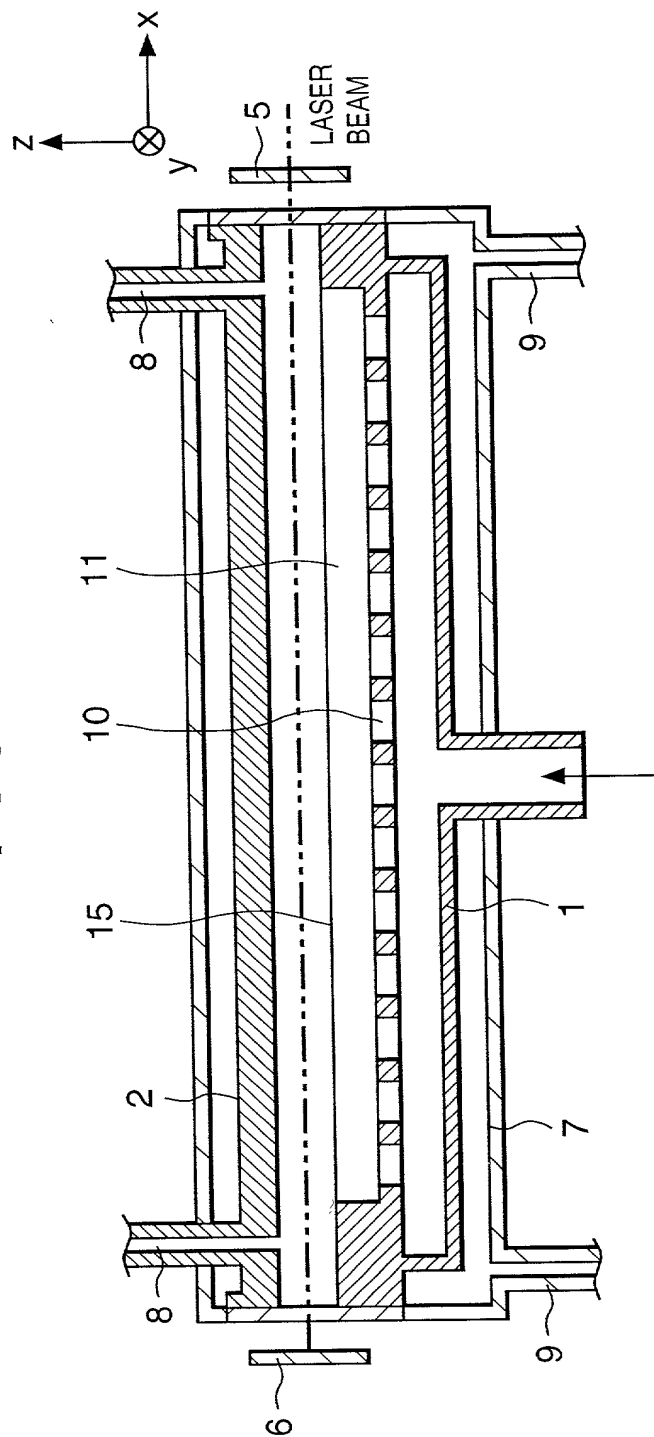


Fig. 1

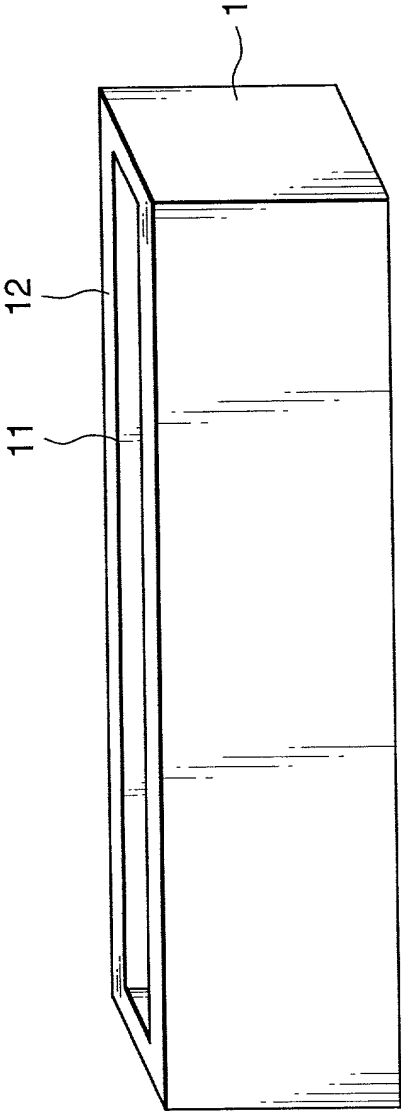


FIG. 2A

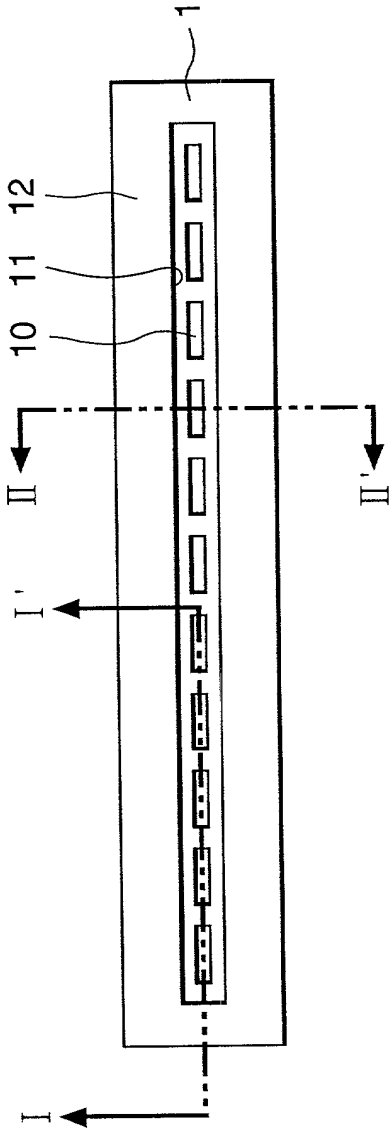


FIG. 2B

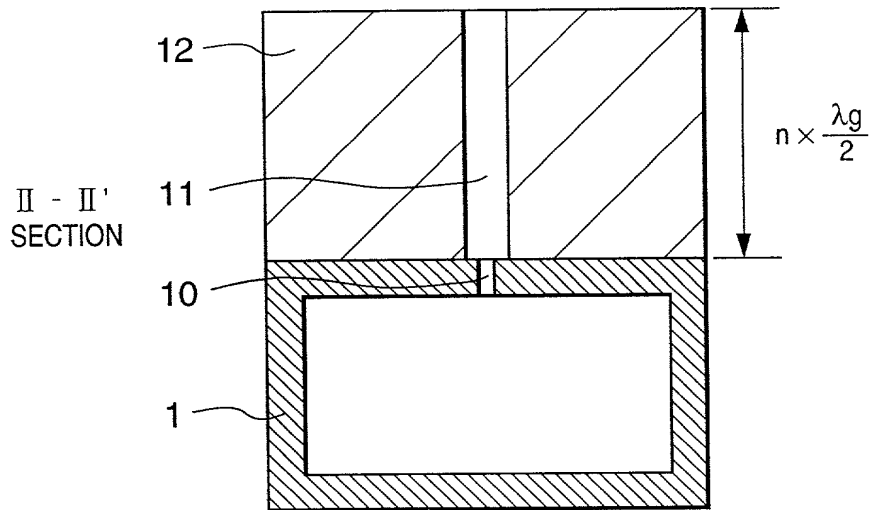
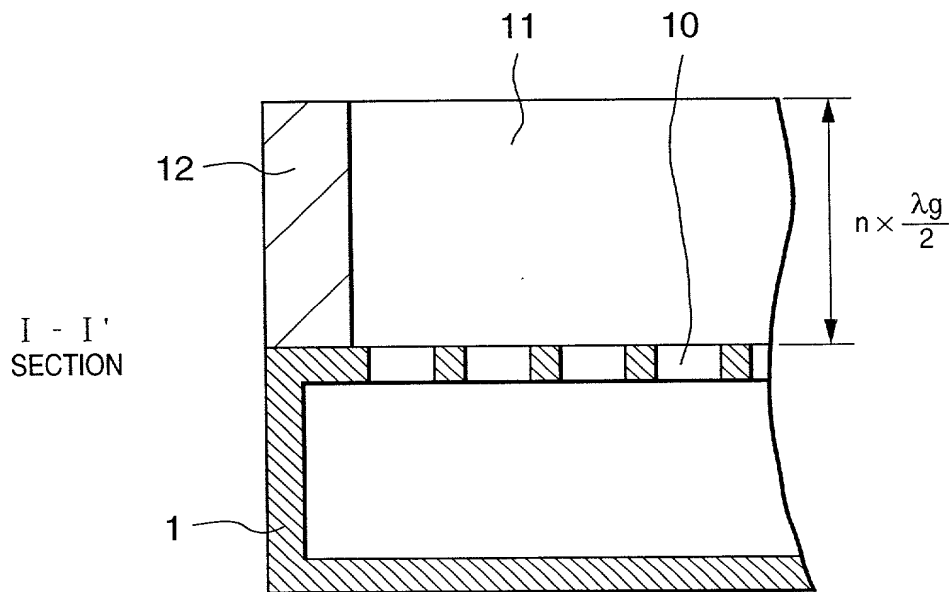
FIG. 3A**FIG. 3B**

FIG. 4

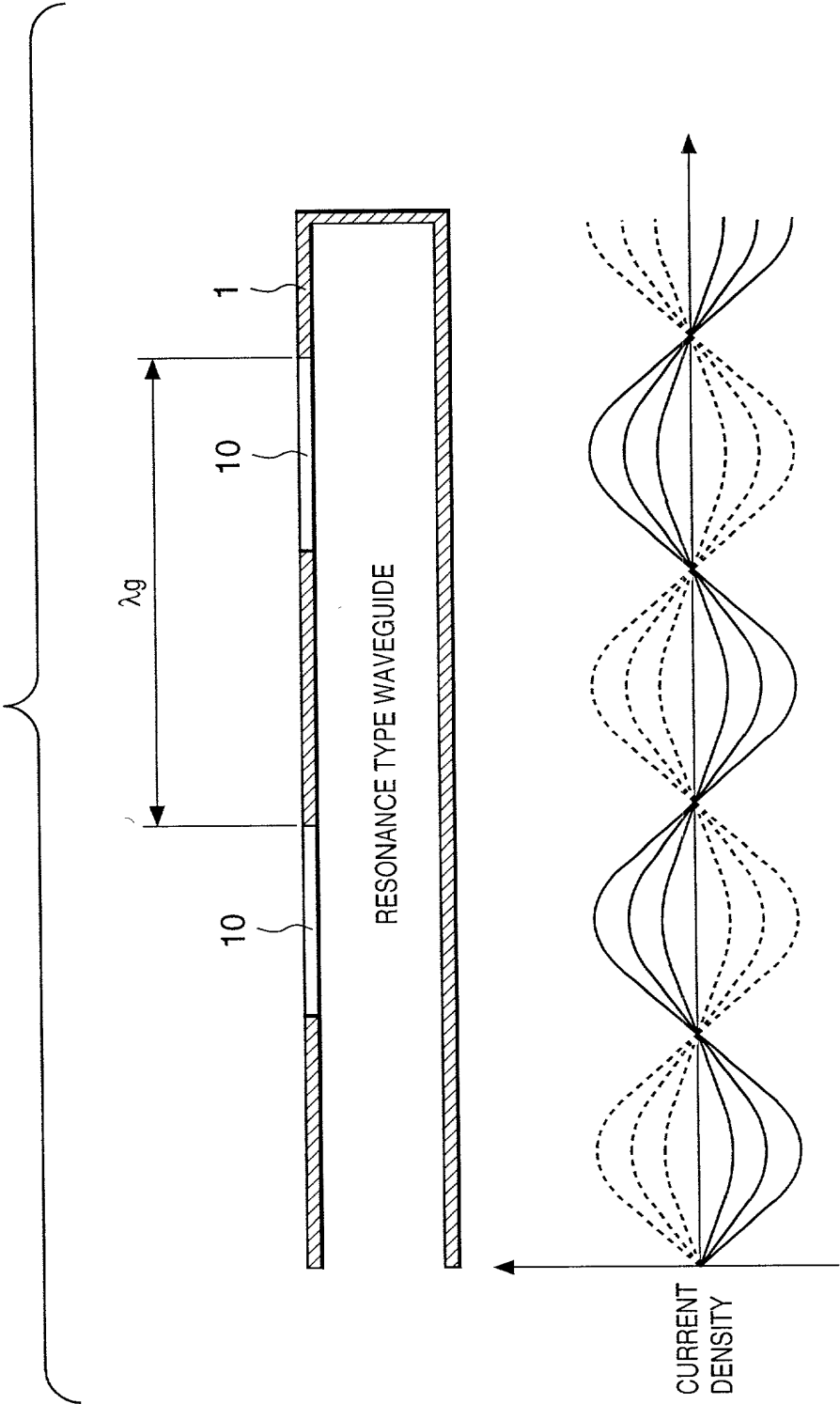


FIG. 5

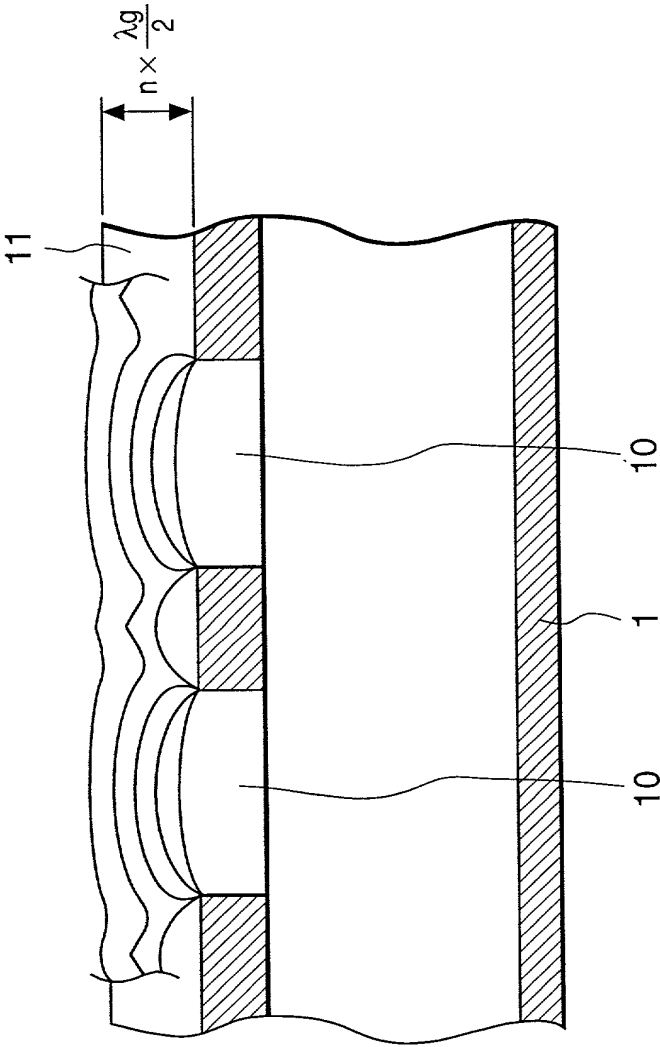


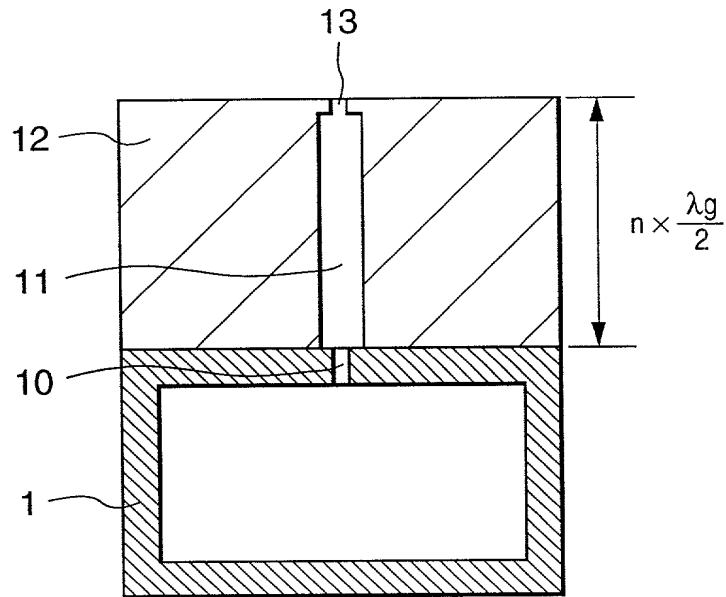
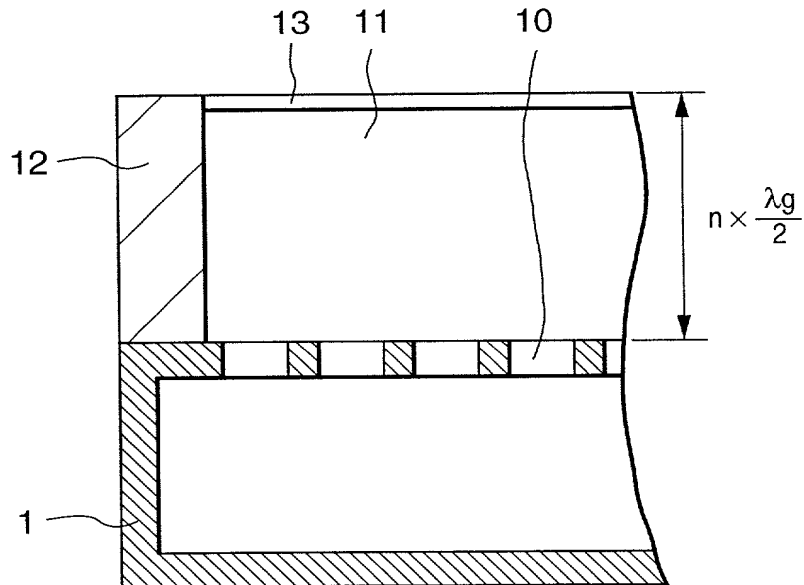
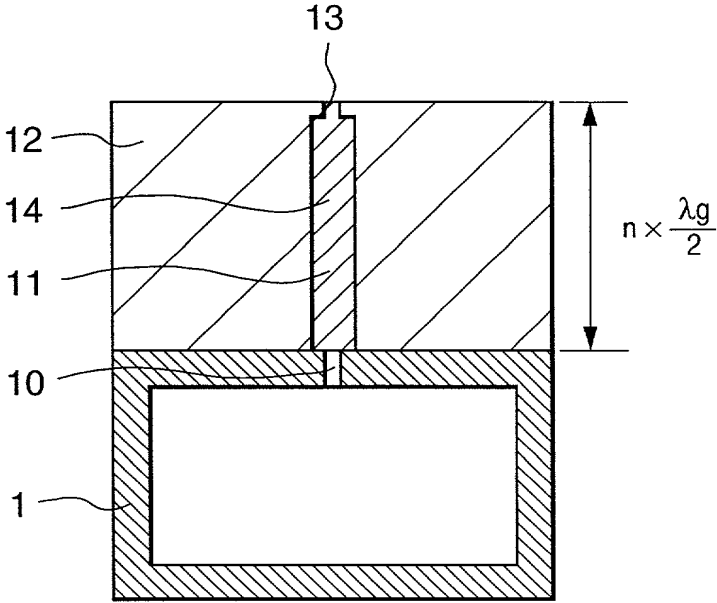
FIG. 6A**FIG. 6B**

FIG. 8



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FIG. 9A

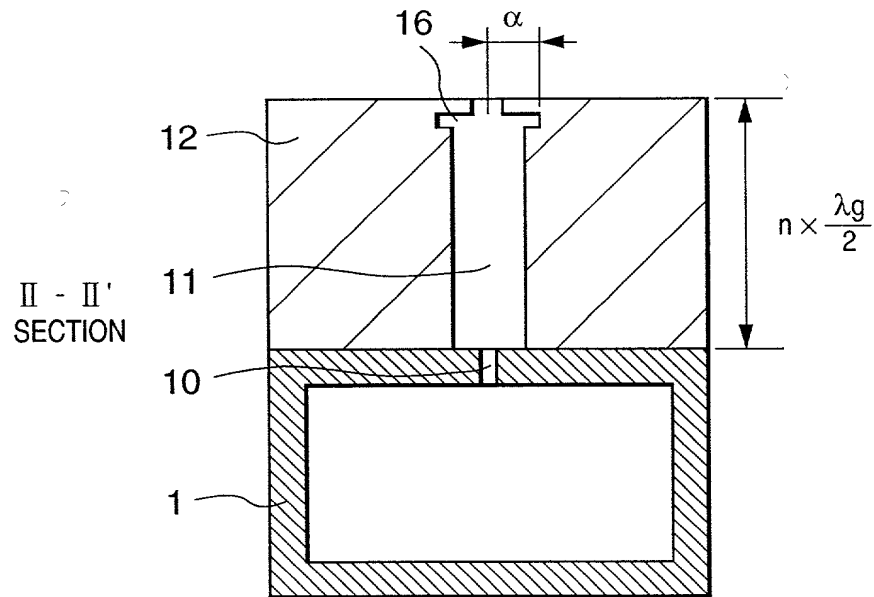


FIG. 9B

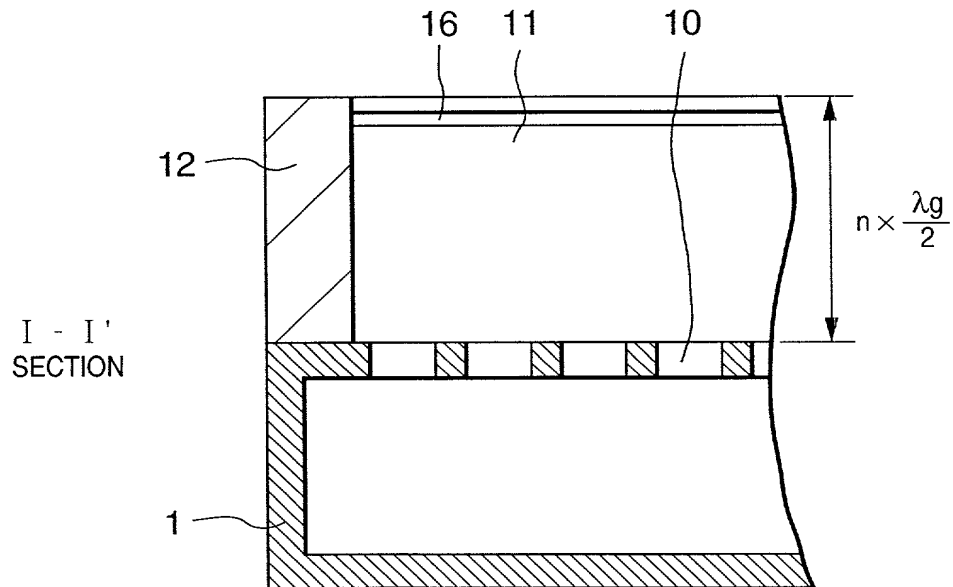


FIG. 10

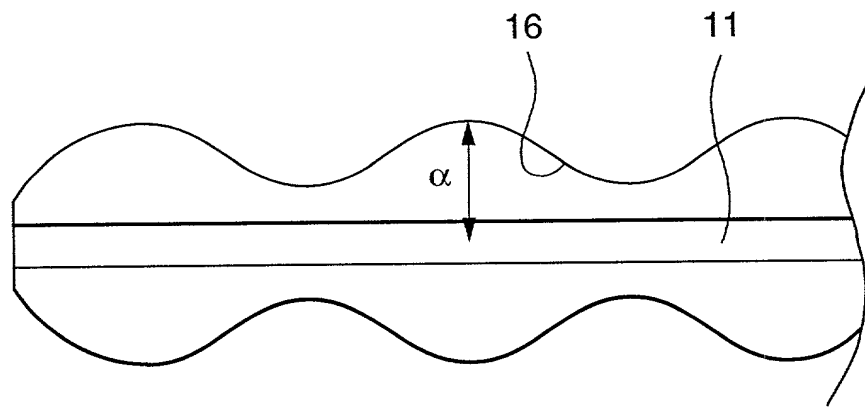


FIG. 11

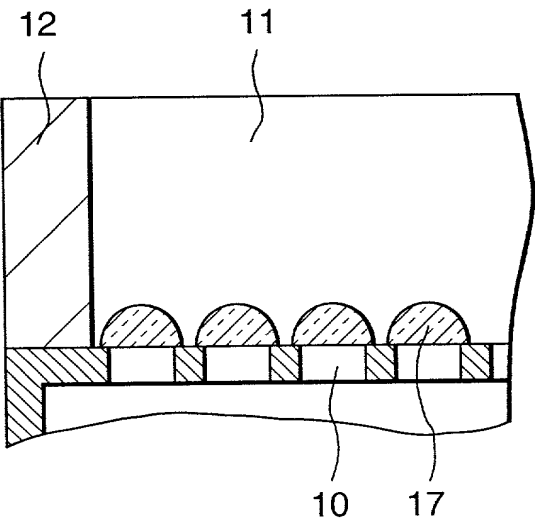
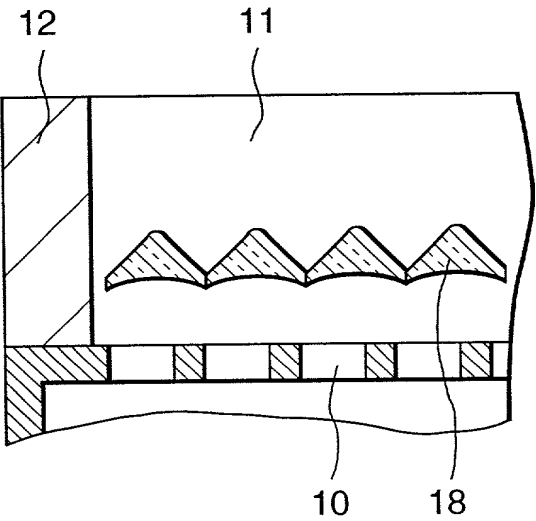


FIG. 12



continued on next page

FIG. 13A

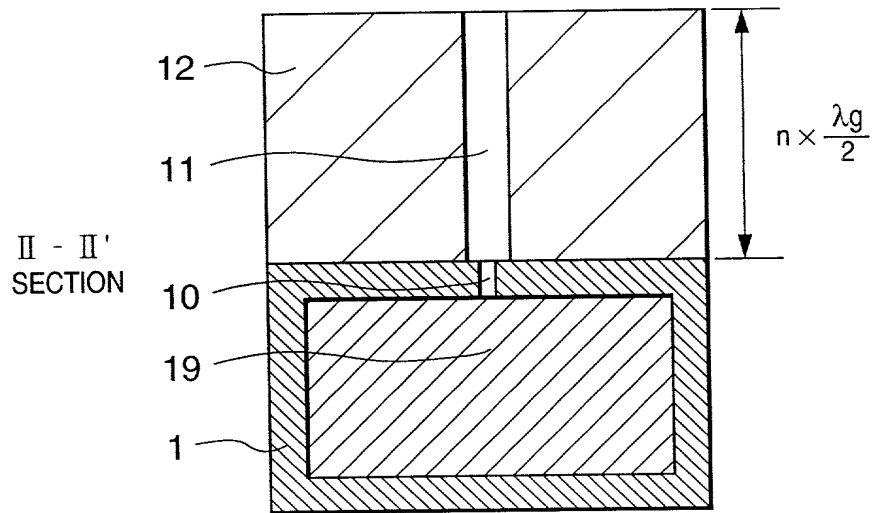


FIG. 13B

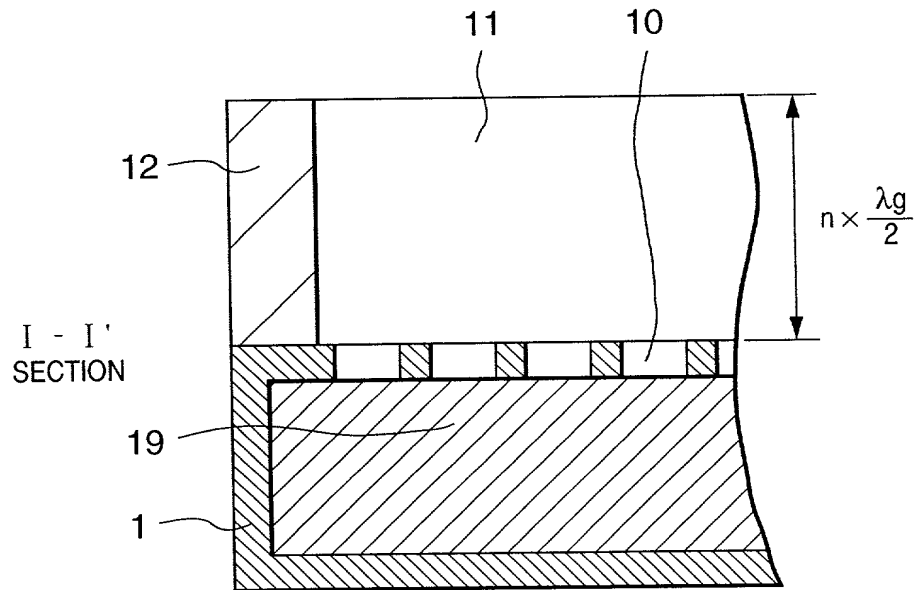
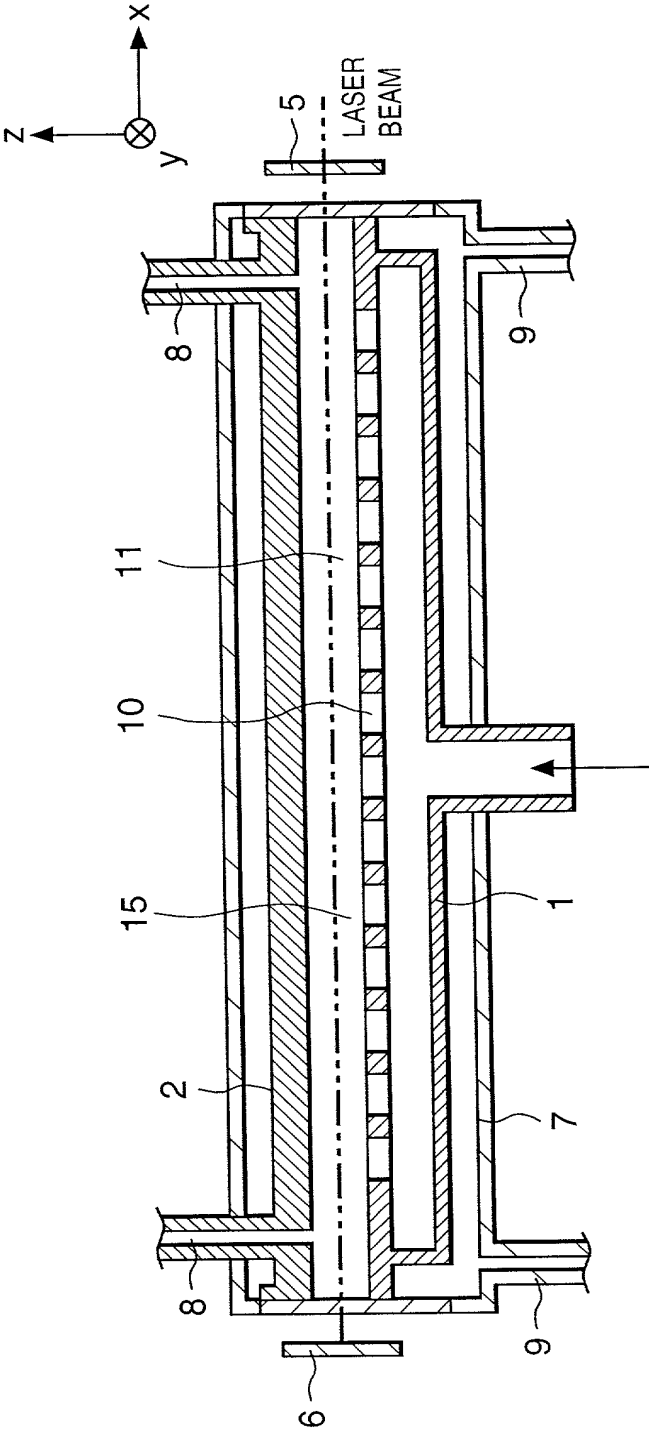


FIG. 14



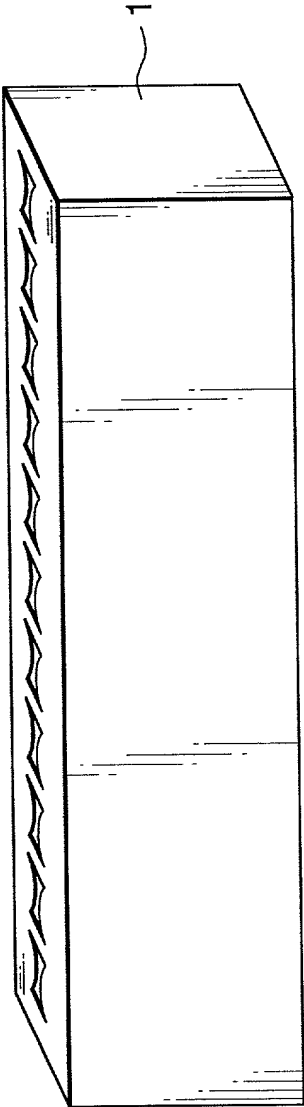


FIG. 15A

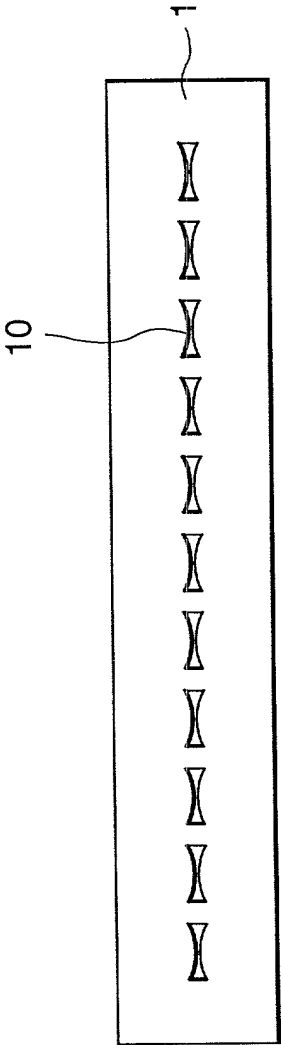


FIG. 15B

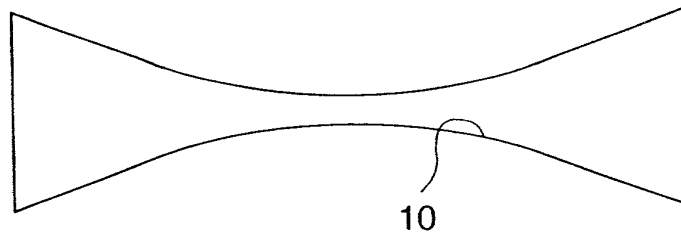
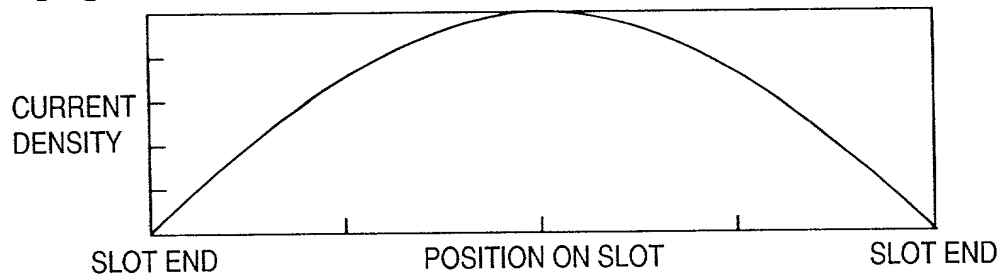
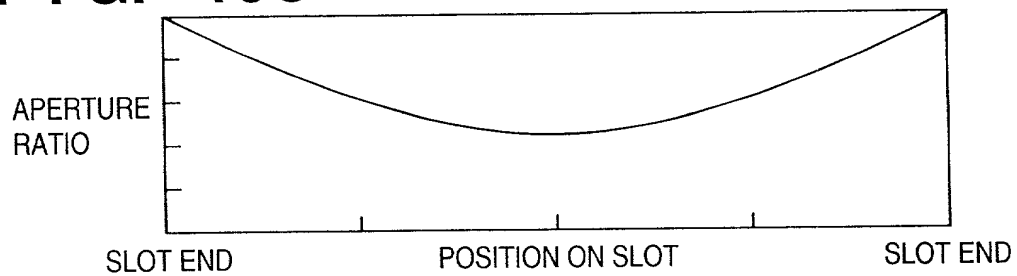
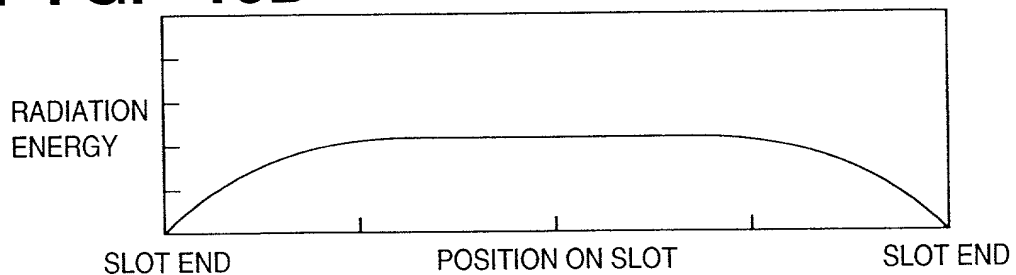
FIG. 16A**FIG. 16B****FIG. 16C****FIG. 16D**

FIG. 17A

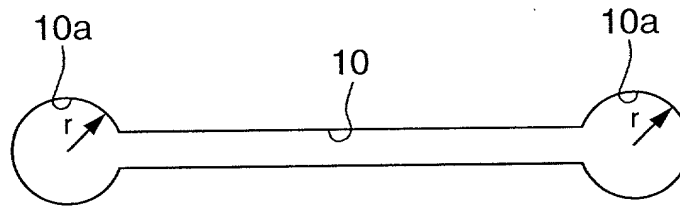


FIG. 17B

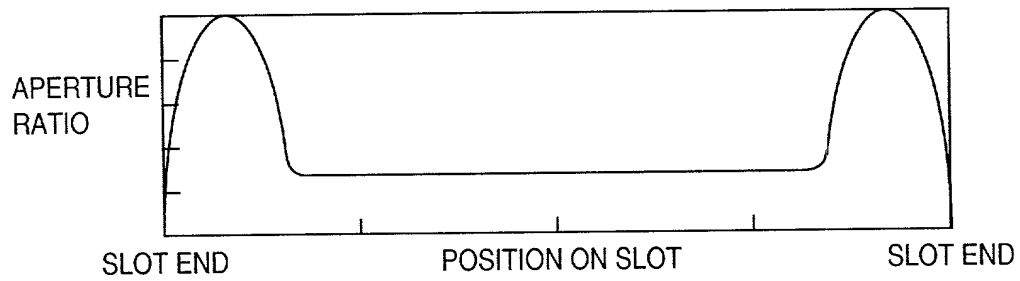


FIG. 17C

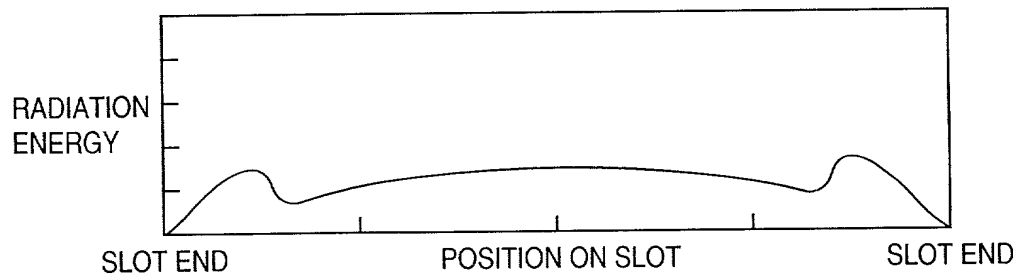


FIG. 18A

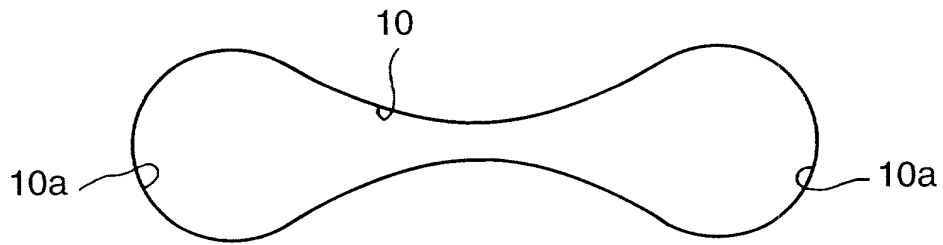


FIG. 18B

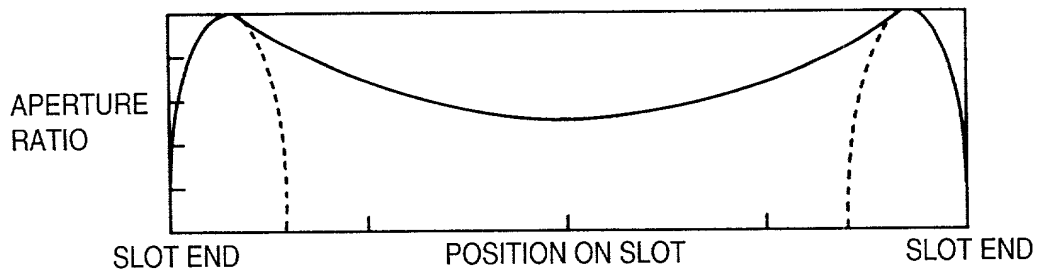


FIG. 18C

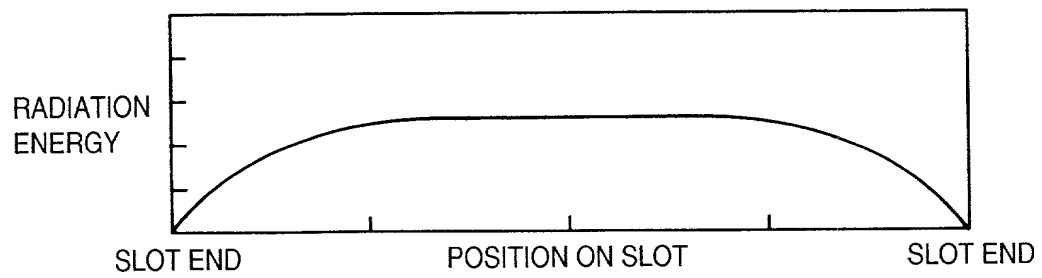


FIG. 19A

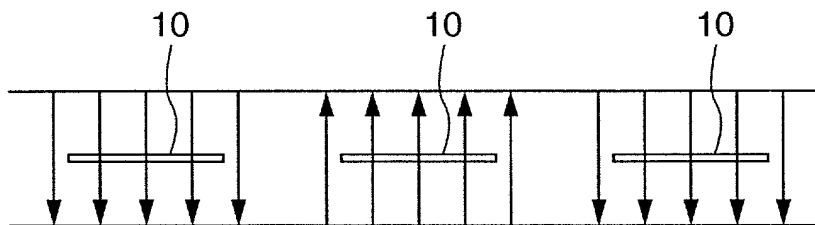


FIG. 19B

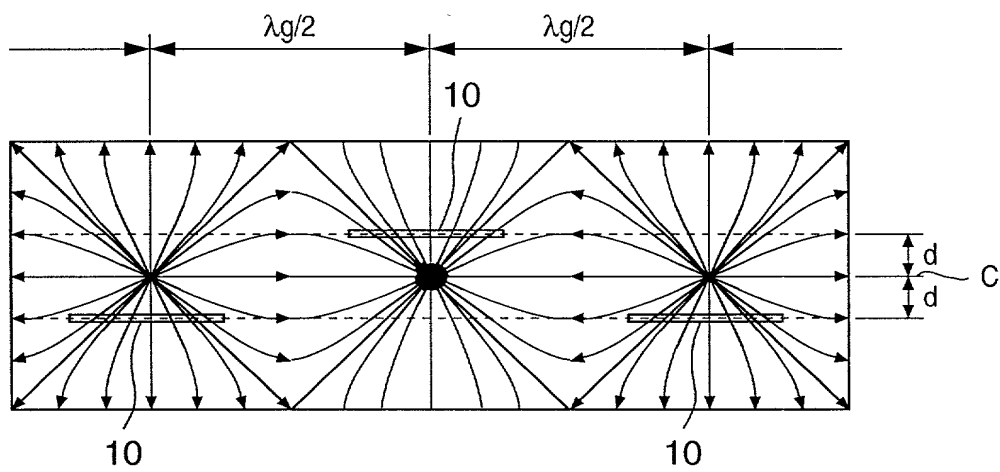


FIG. 19C

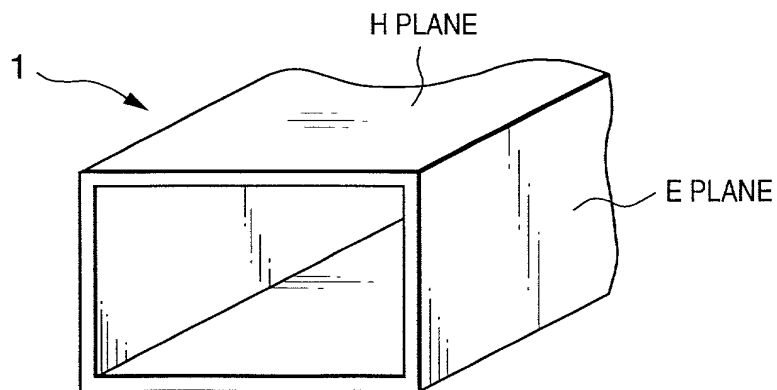


FIG. 20A

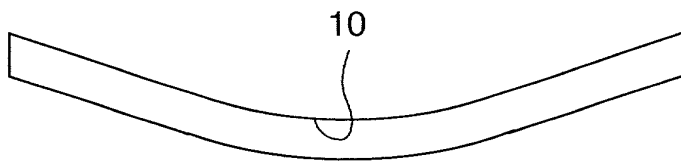


FIG. 20B

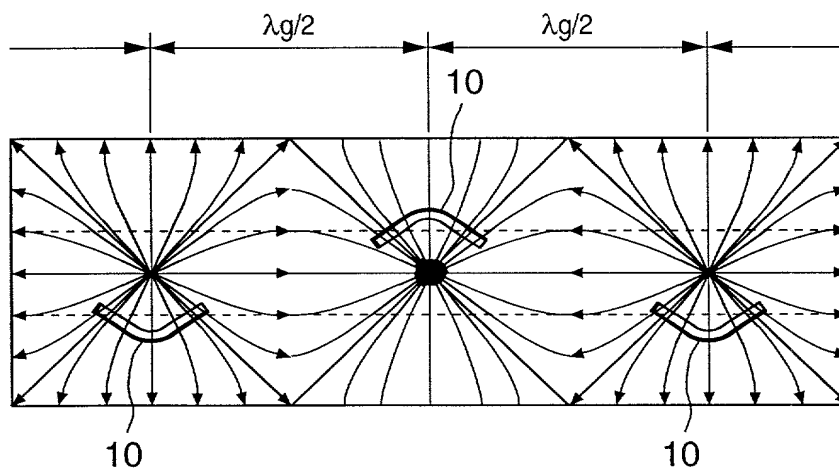


FIG. 21B

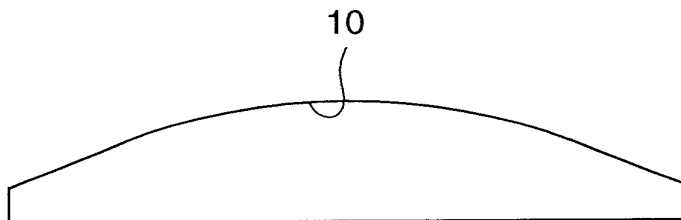


FIG. 22A

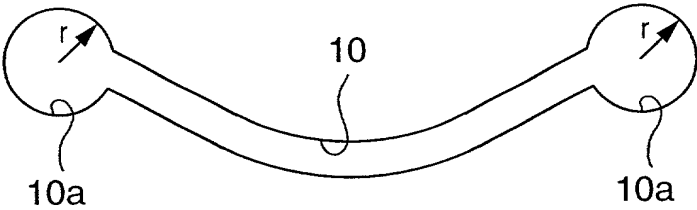


FIG. 22B

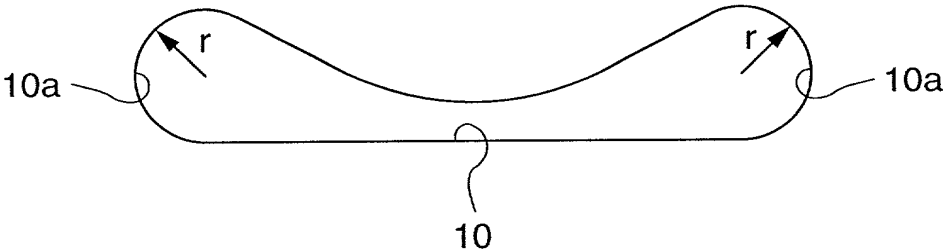


FIG. 23

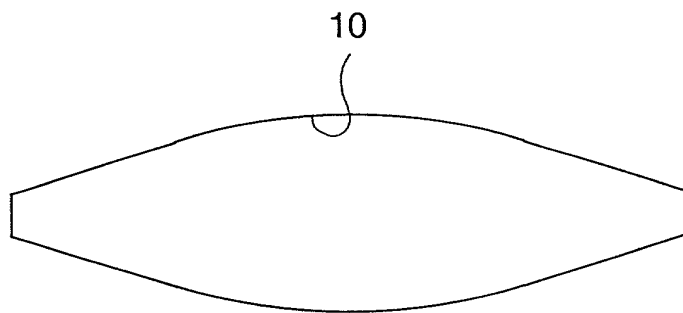


FIG. 24A

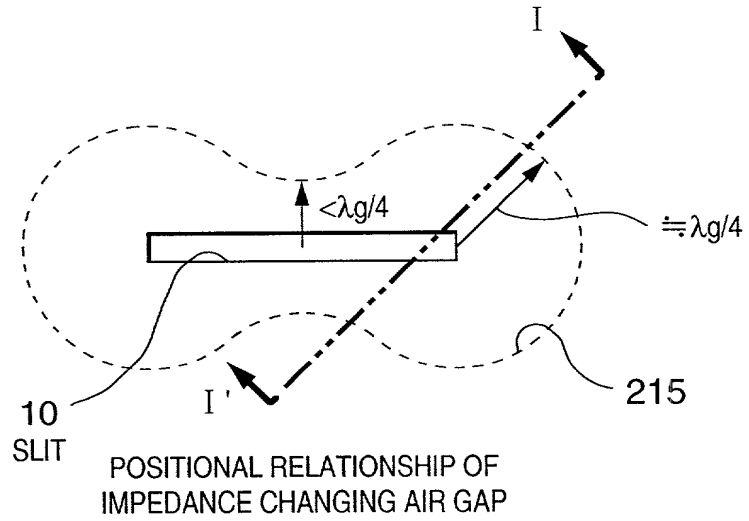
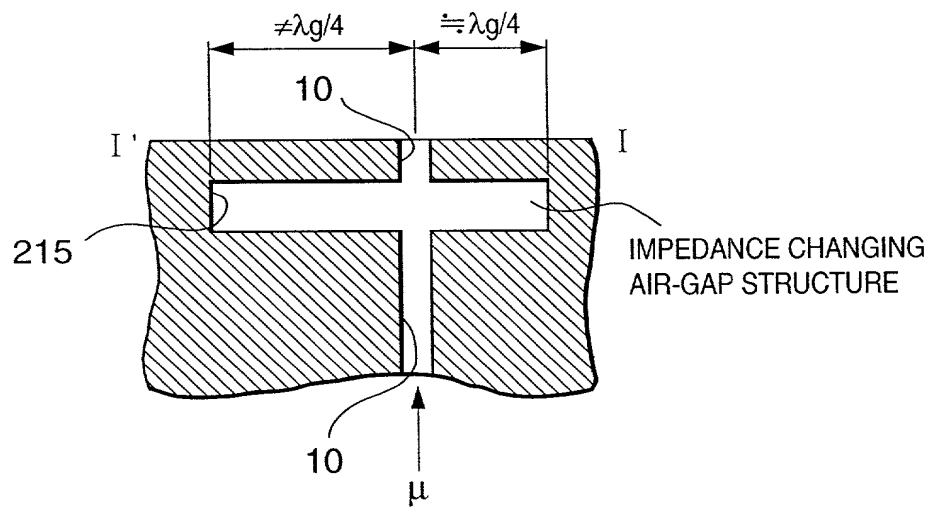


FIG. 24B



SECTIONAL VIEW (I - I ') OF
IMPEDANCE CHANGING AIR GAP

FIG. 25A

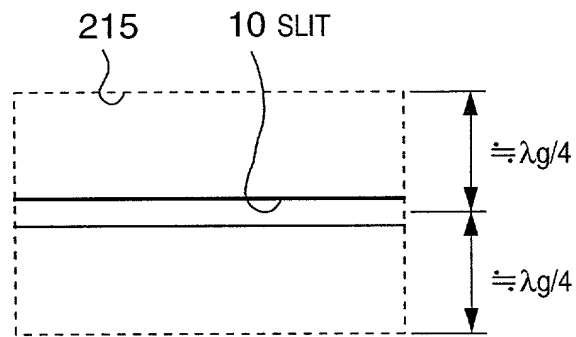
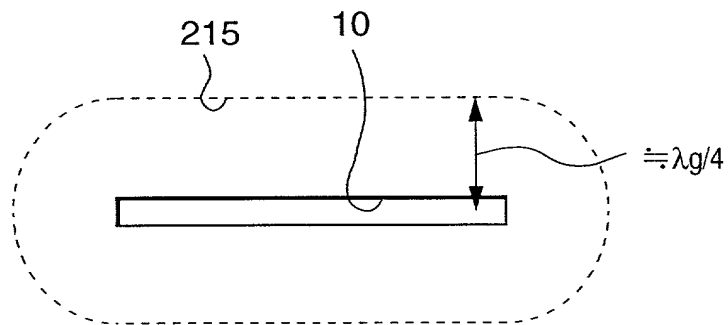


FIG. 25B



POSITIONAL RELATIONSHIP OF
 $\lambda g/4$ -LONG AIR-GAP STRUCTURE

FIG. 26A

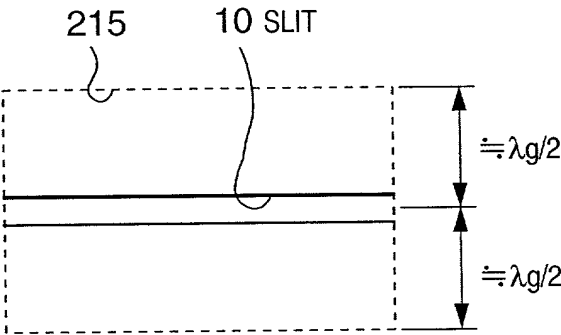
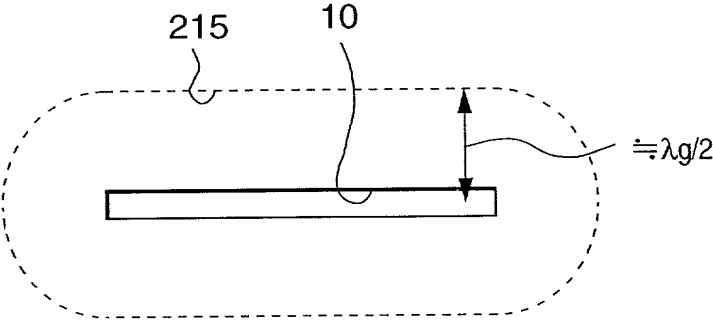
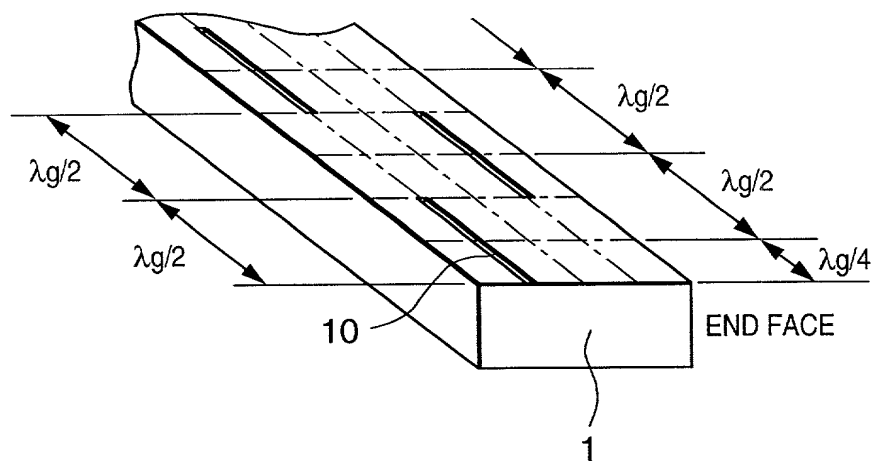


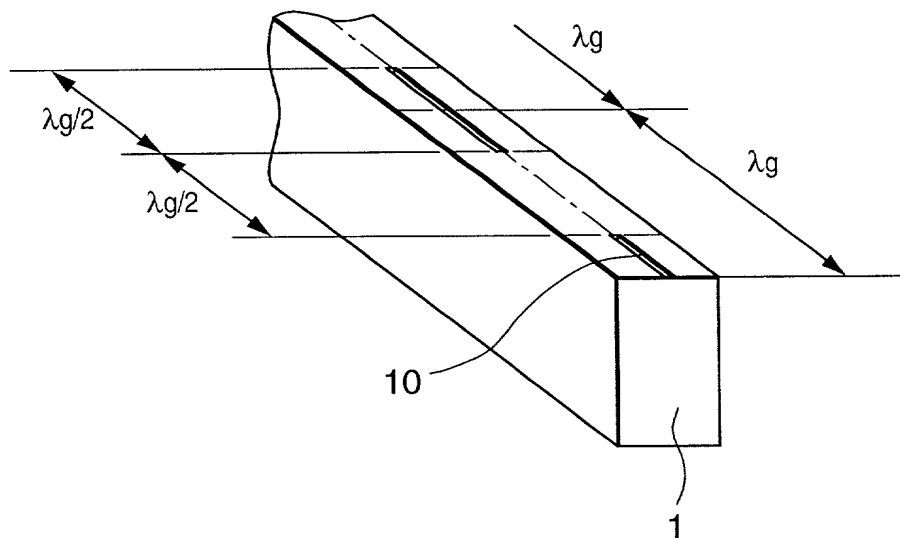
FIG. 26B



POSITIONAL RELATIONSHIP OF
 $\lambda g/2$ -LONG AIR-GAP STRUCTURE

FIG. 27A

RESONANCE LENGTH SLOT $\lambda_g/2$ -PITCH
H-PLANE ANTENNA STRUCTURE

FIG. 27B

RESONANCE LENGTH SLOT λ_g -PITCH
E-PLANE ANTENNA STRUCTURE

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FIG. 28A

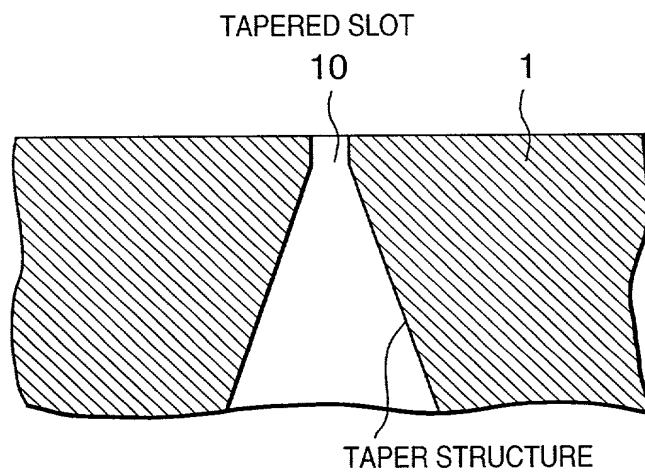


FIG. 28B

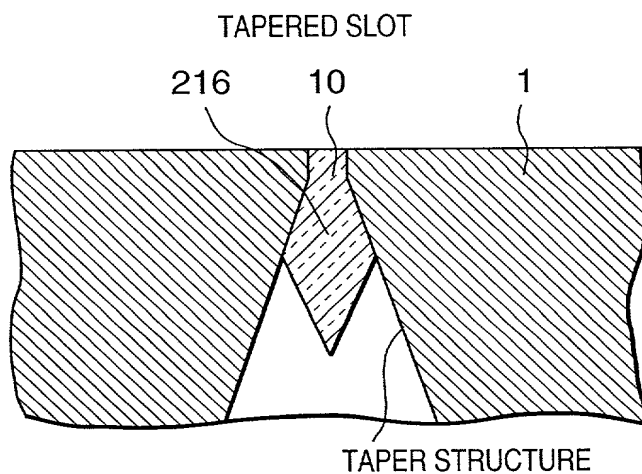


FIG. 28C

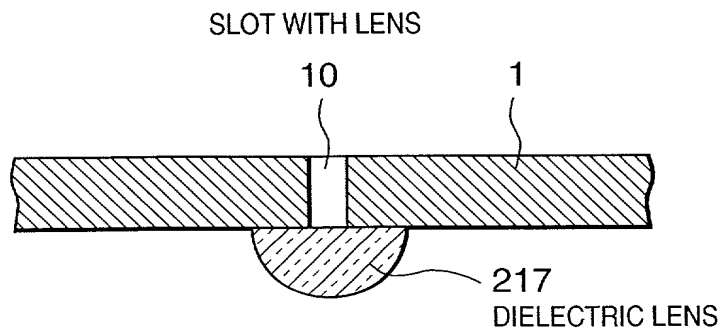
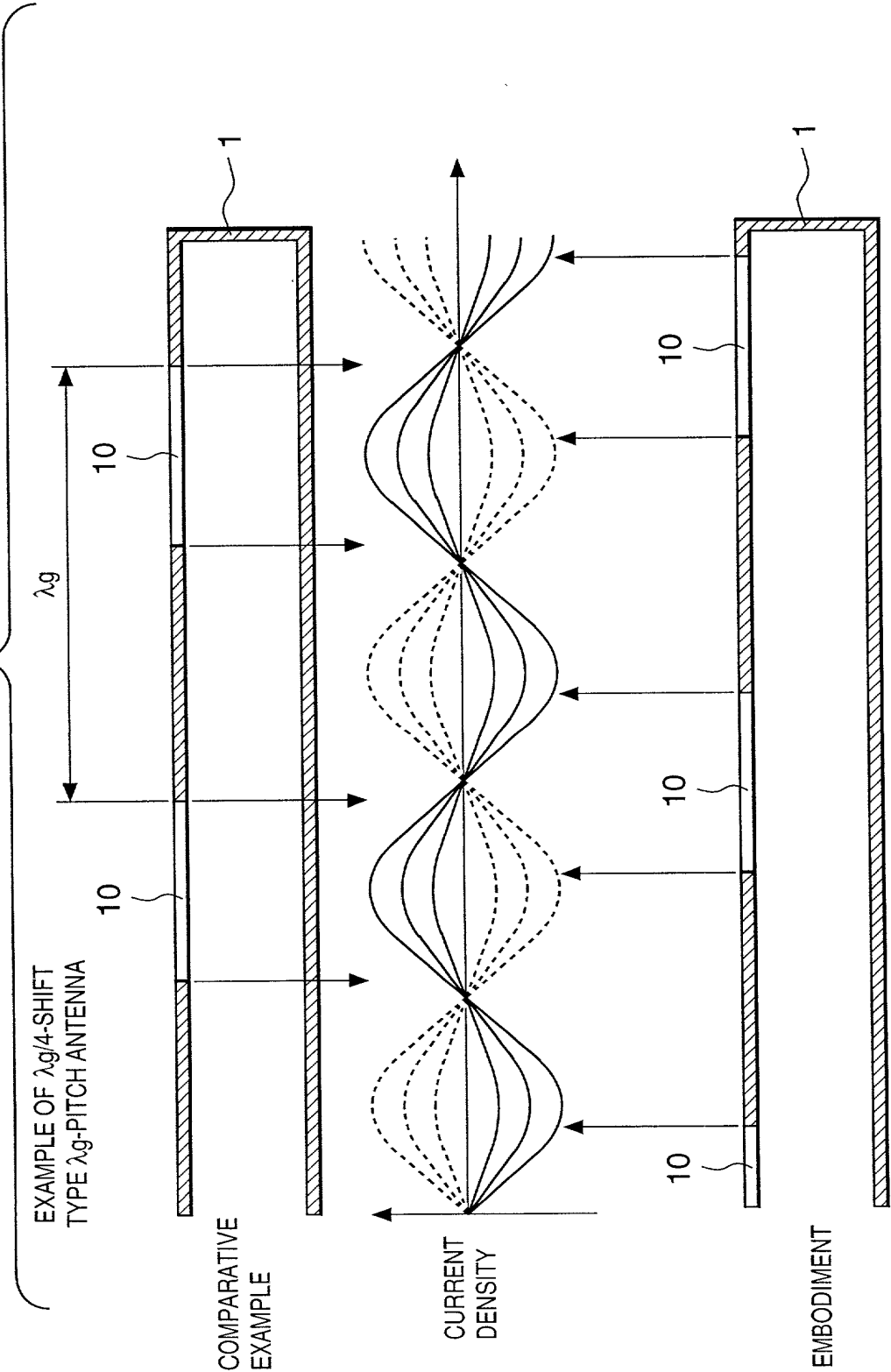


FIG. 29



A diagram illustrating the geometry of a slot. A horizontal line represents the slot's long-axis direction, with an arrow pointing to the right labeled "SLOT LONG-AXIS DIRECTION". A vertical line represents the slot's center, with an arrow pointing upwards. The intersection of these lines is labeled "SLOT CENTER". Two curved lines, representing the slot's profile, are shown on either side of the center, each labeled "SLOT END".

FIG. 31

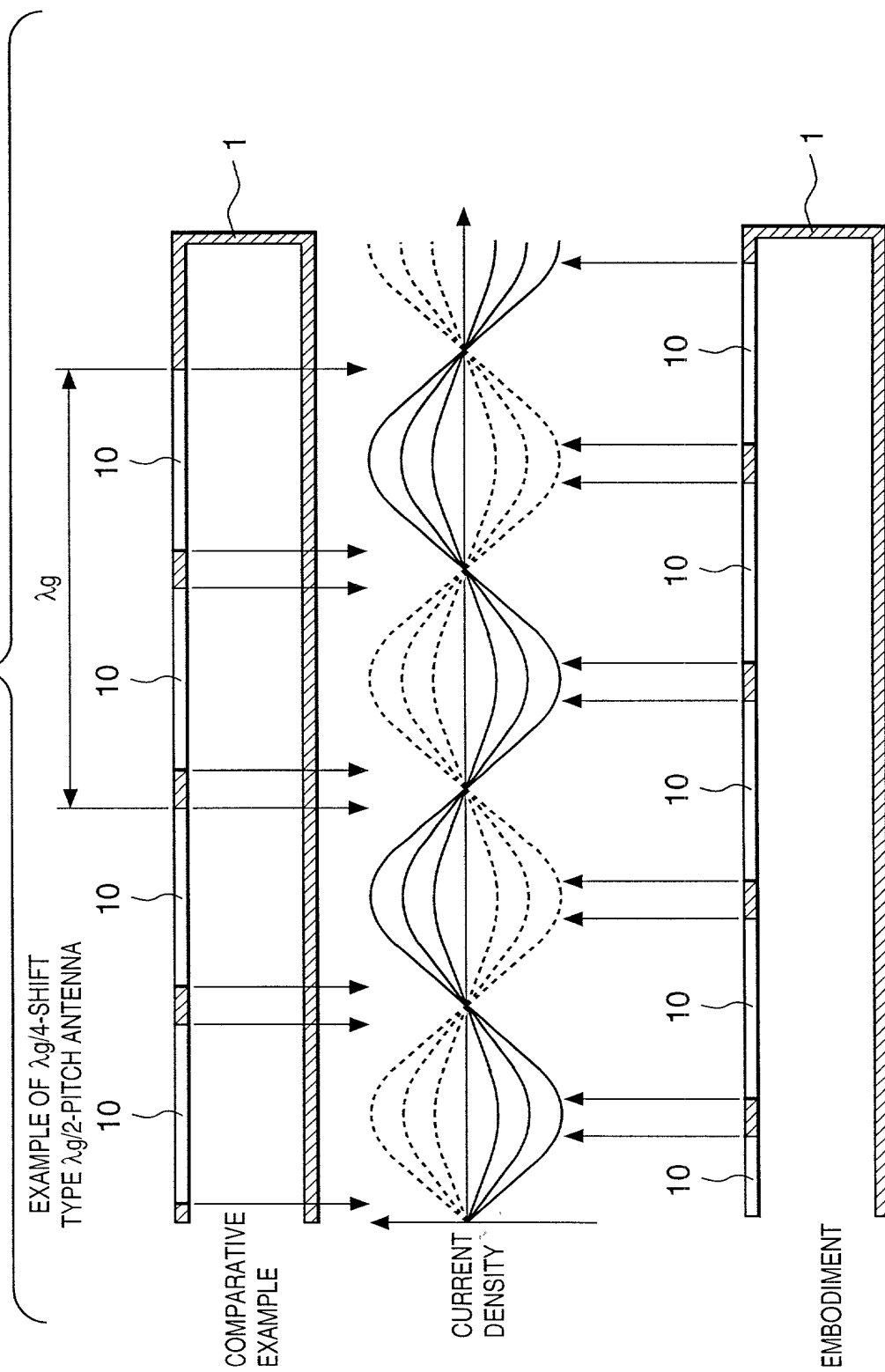


FIG. 32C

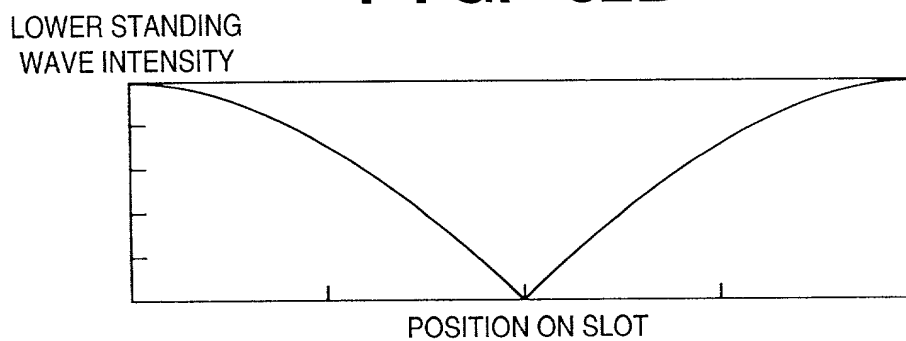
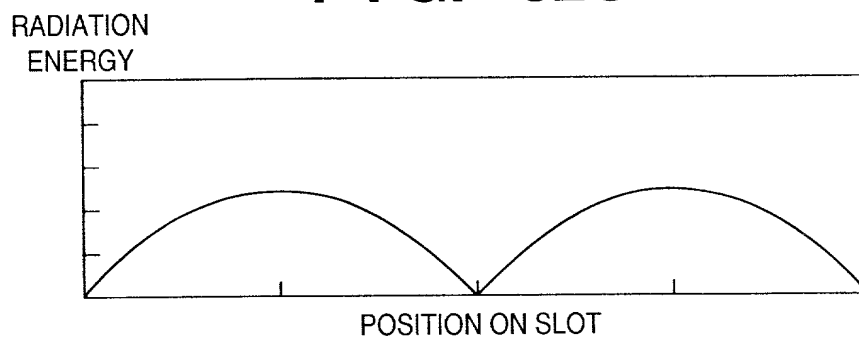


FIG. 32C



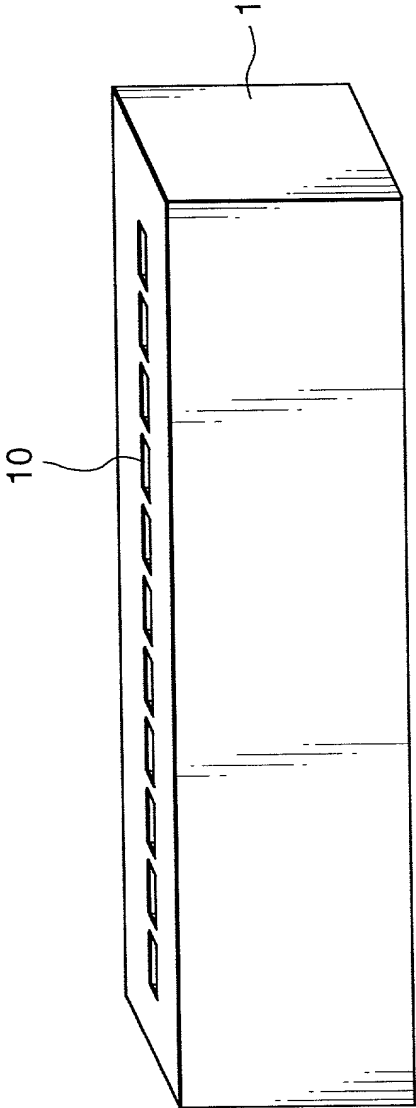


FIG. 33A

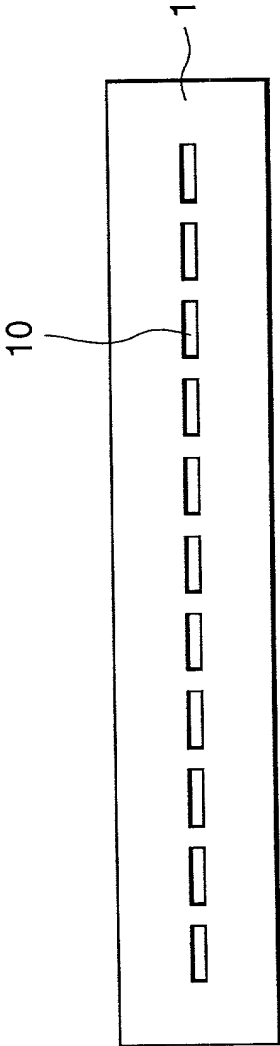


FIG. 33B

FIG. 34A

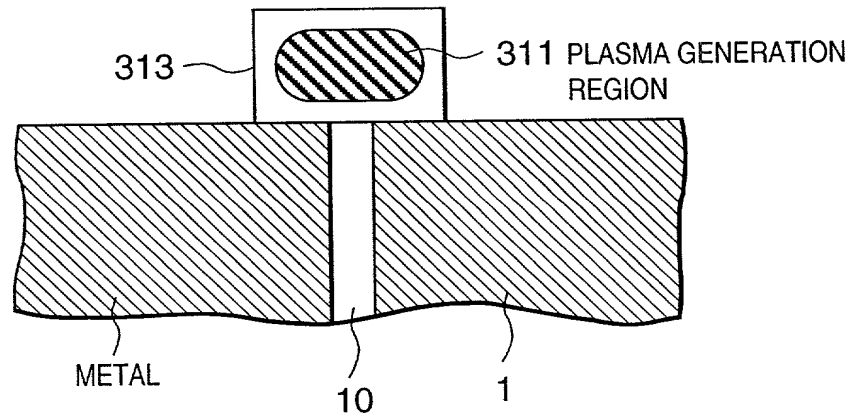


FIG. 34B

SECTION VIEWED IN DIRECTION
PERPENDICULAR TO SLOT LONG-AXIS DIRECTION

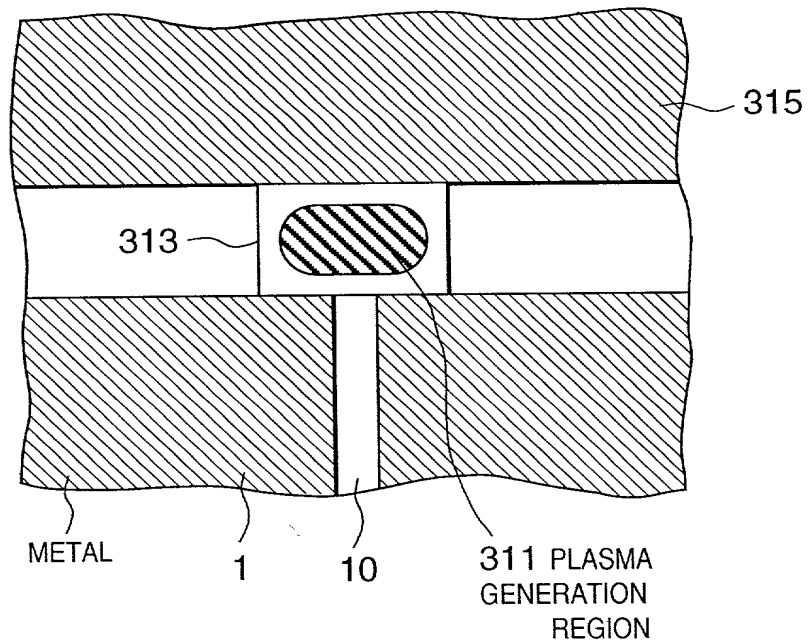


FIG. 35A

PLAN VIEW OF NOZZLE SHIELD

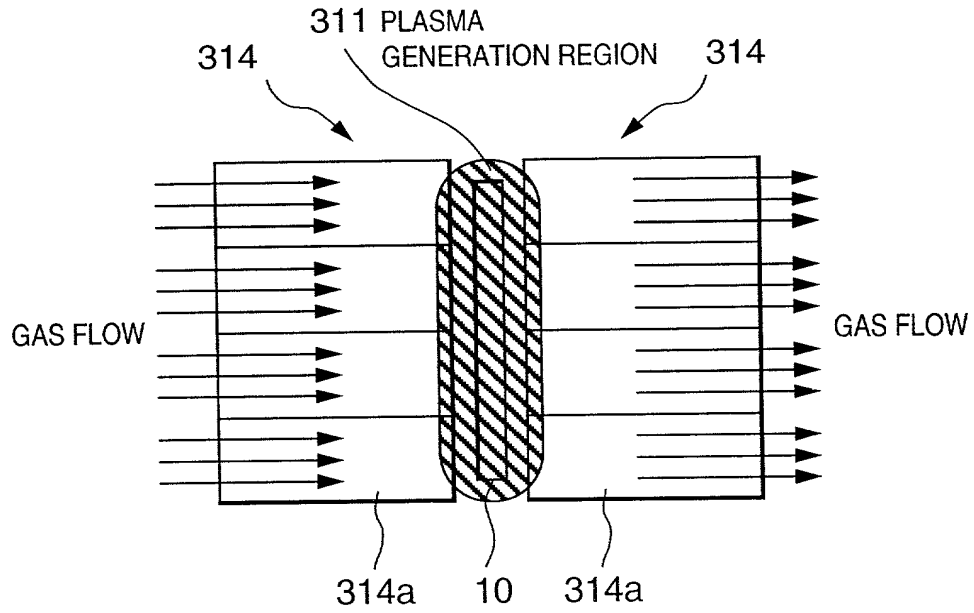


FIG. 35B

OUTLINE OF NOZZLE SHIELD

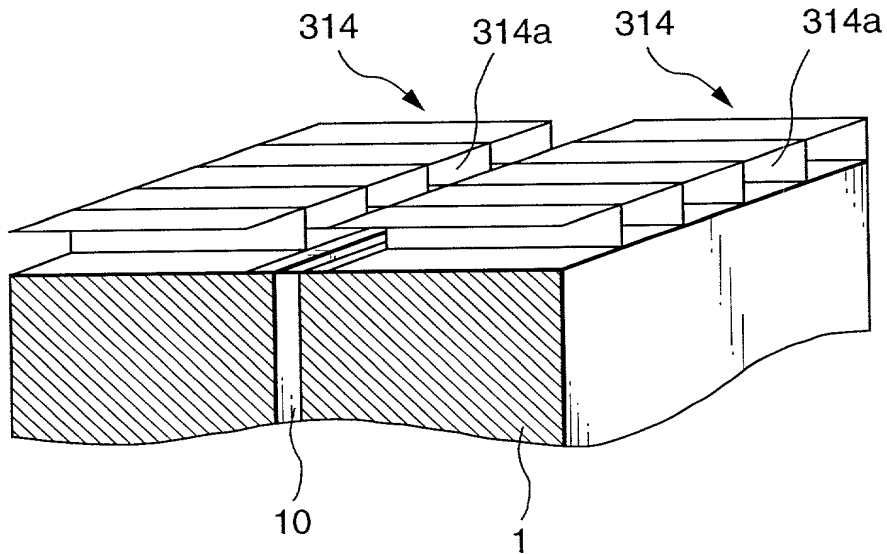


FIG. 36A

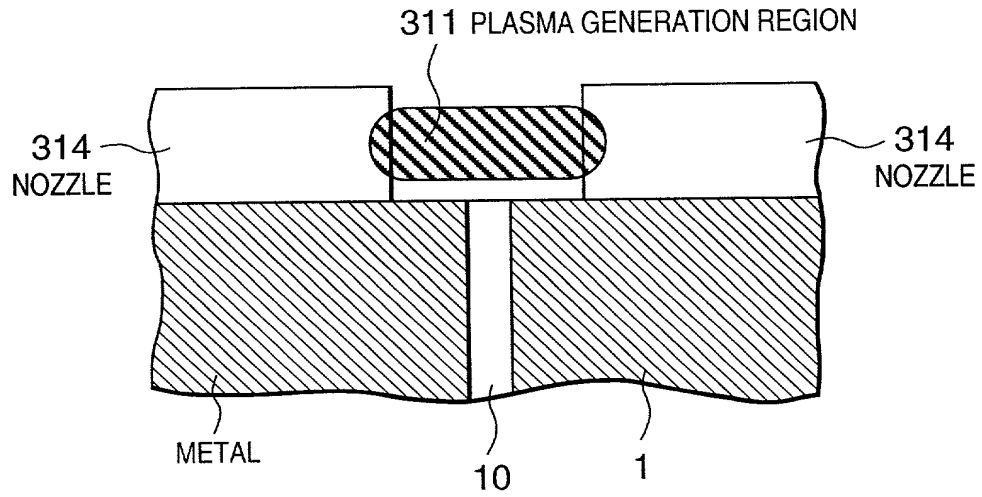


FIG. 36B

SECTION VIEWED IN SLOT
SHORT-AXIS DIRECTION

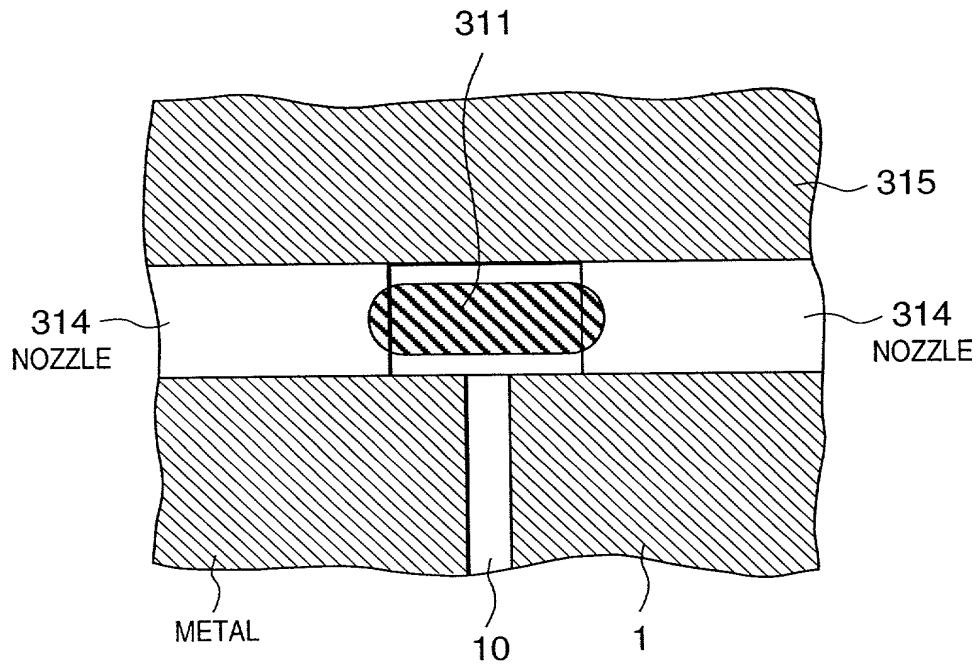


FIG. 37A

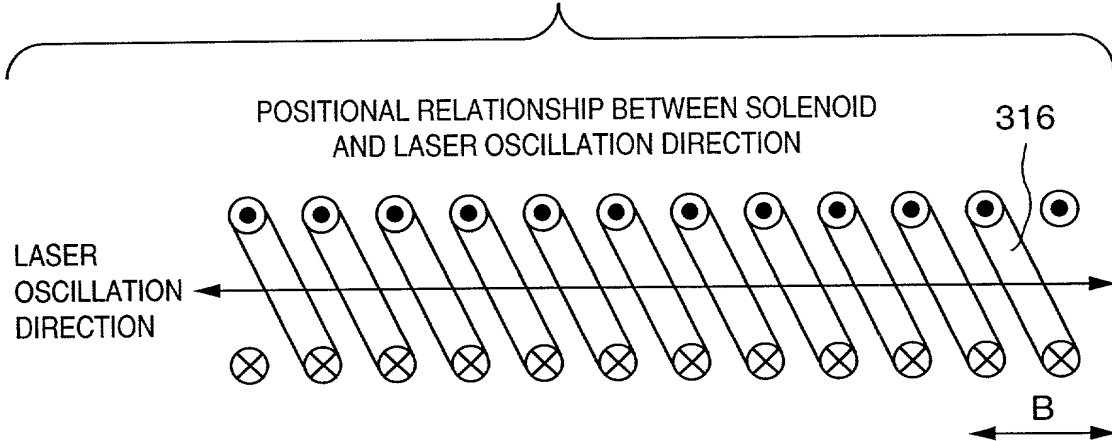


FIG. 37B

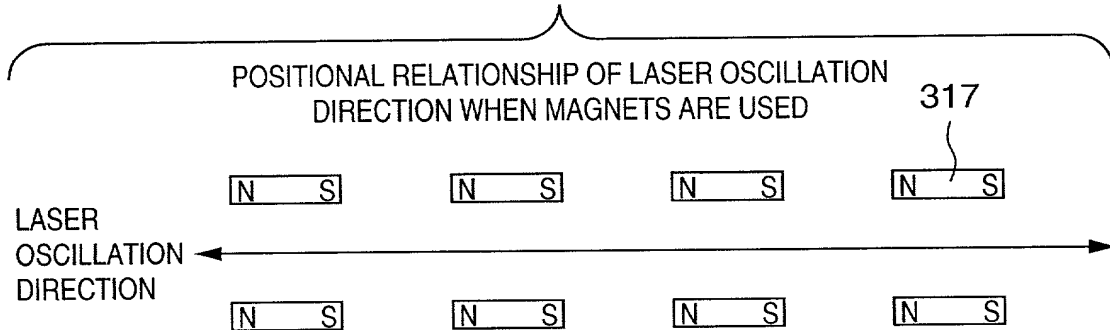


FIG. 38A

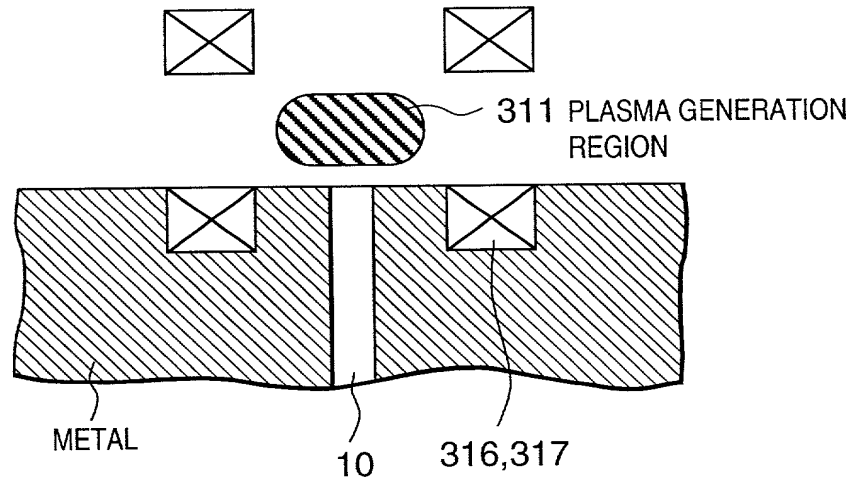


FIG. 38B

SECTION VIEWED IN SLOT SHORT-AXIS DIRECTION
(DIRECTION OF MAGNETIC FIELD IS
PERPENDICULAR TO PAPER SURFACE)

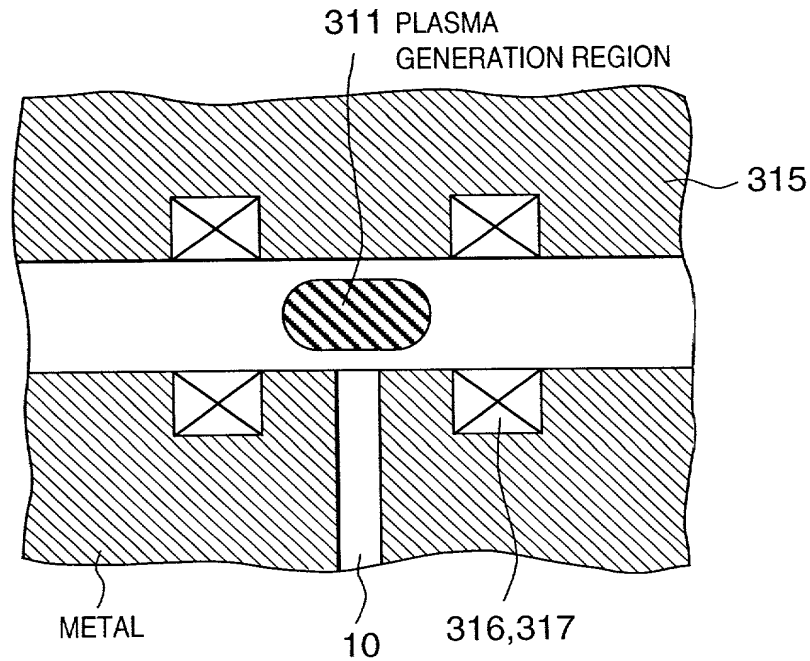


FIG. 39

NOZZLE SLOT-MAGNETIC FIELD COMPOSITE
TYPE CONFINING STRUCTURE

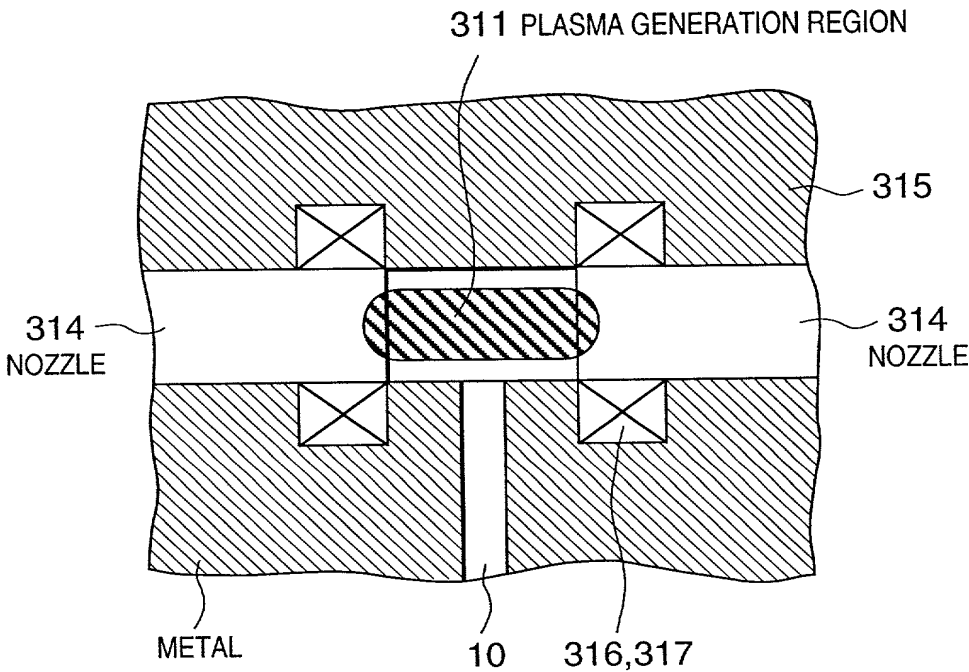


FIG. 40

WHEN SLOT WIDTH IS SMALL

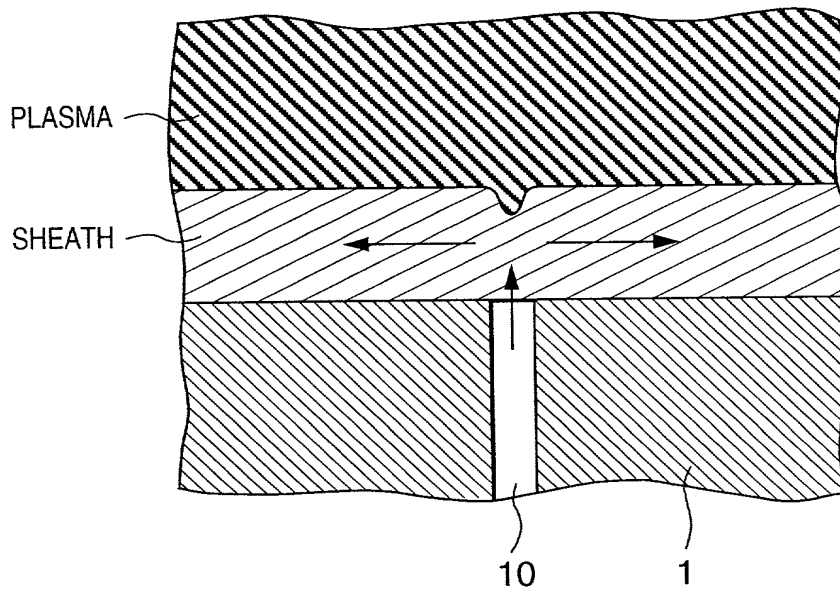


FIG. 41

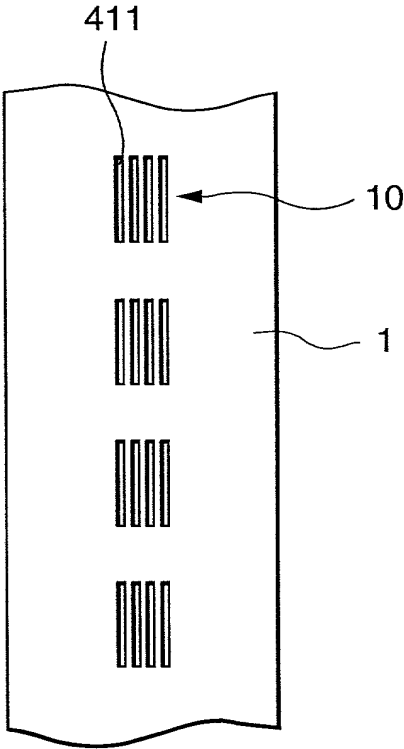


FIG. 42

WHEN SLOT WIDTH IS SMALL

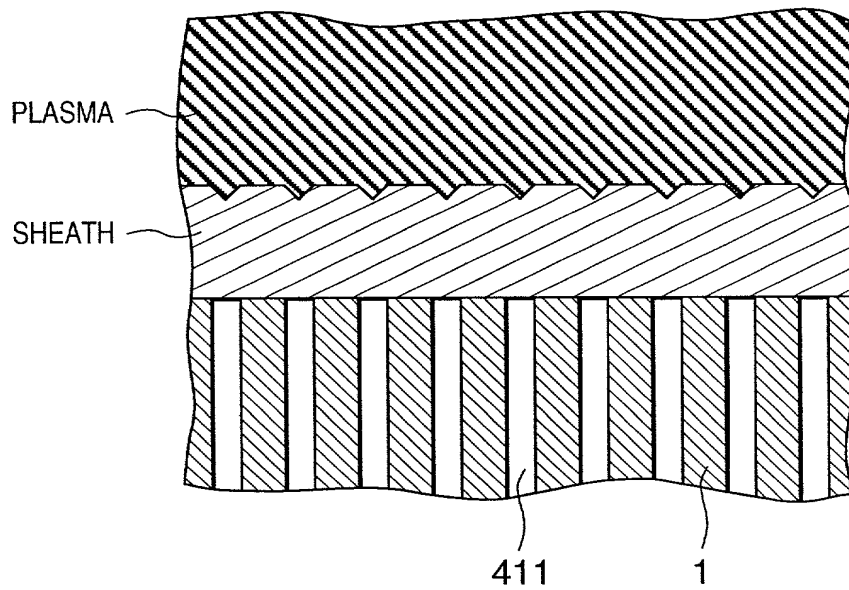


FIG. 43

WHEN SLOT WIDTH IS SMALL

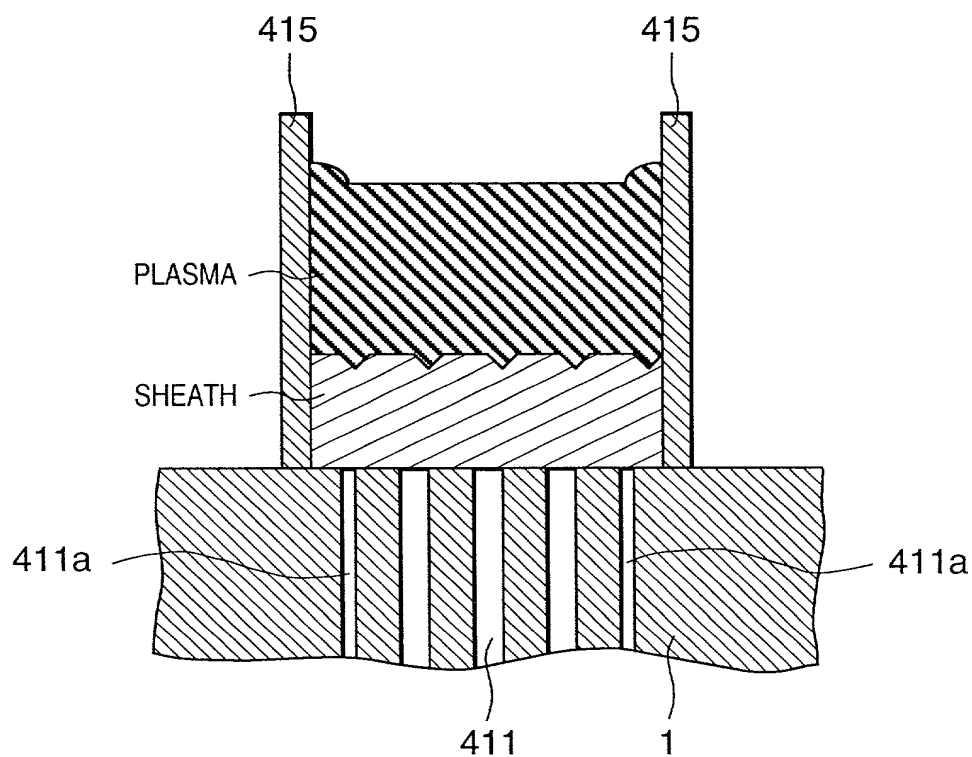
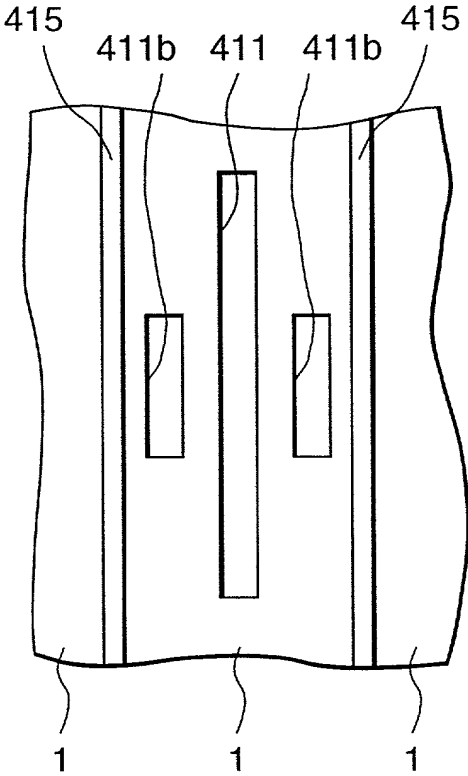


FIG. 44



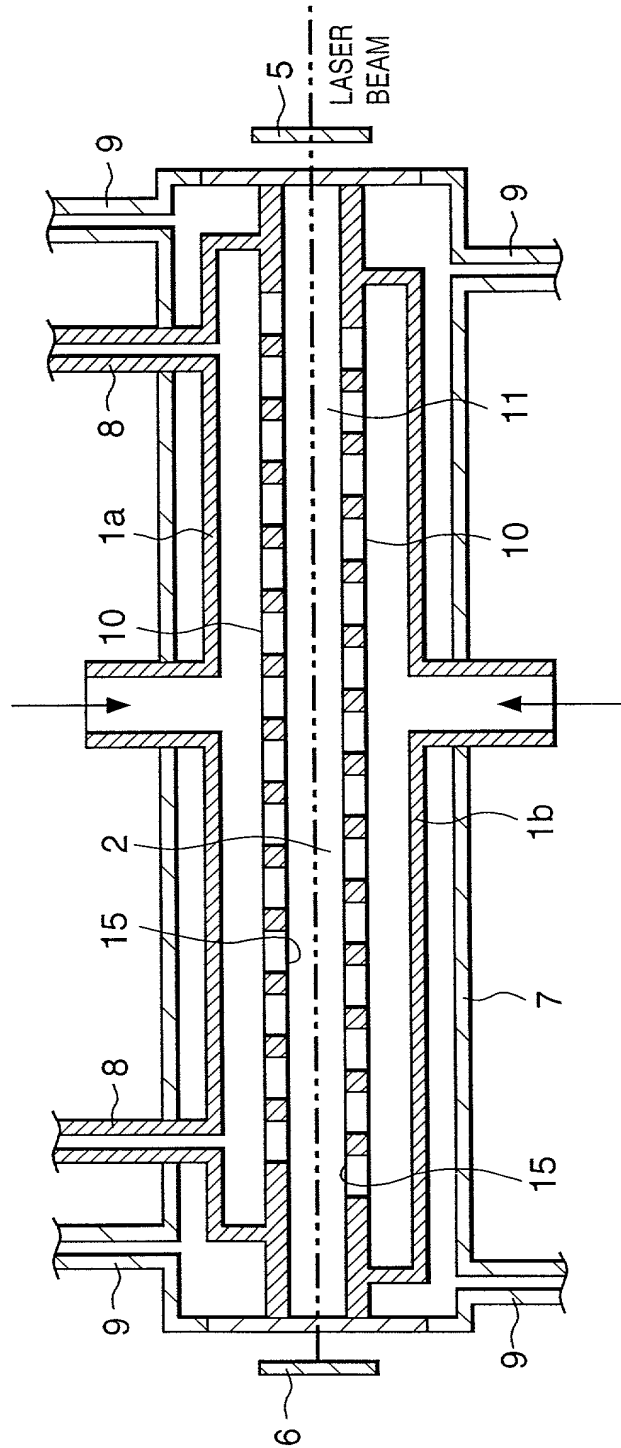
[illegible]

FIG. 46

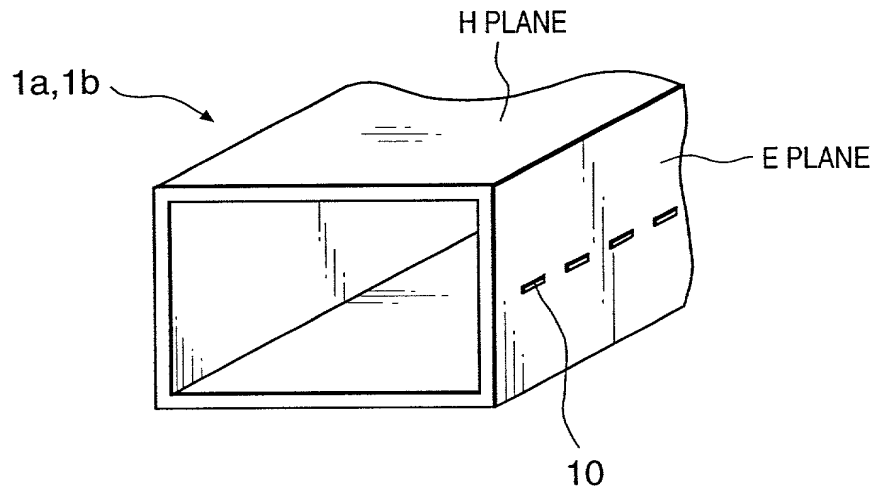


FIG. 47

RELATIVE POSITION TO
NORMAL WAVEGUIDE END $1/\lambda g$

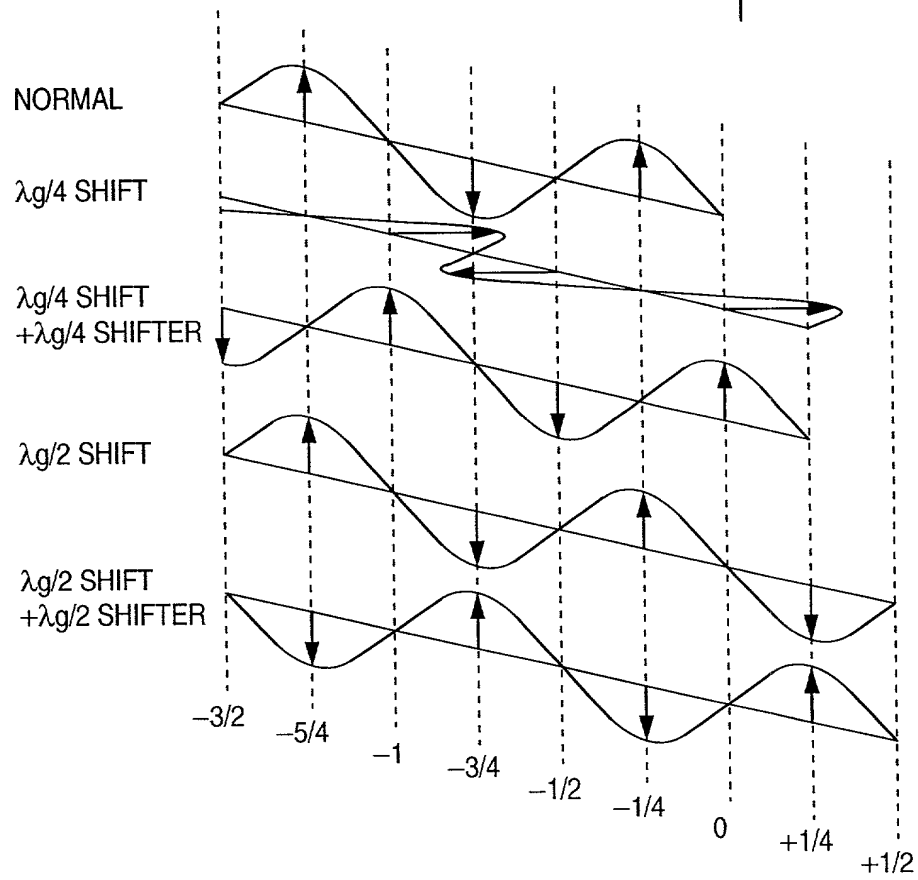
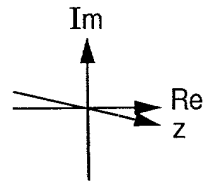
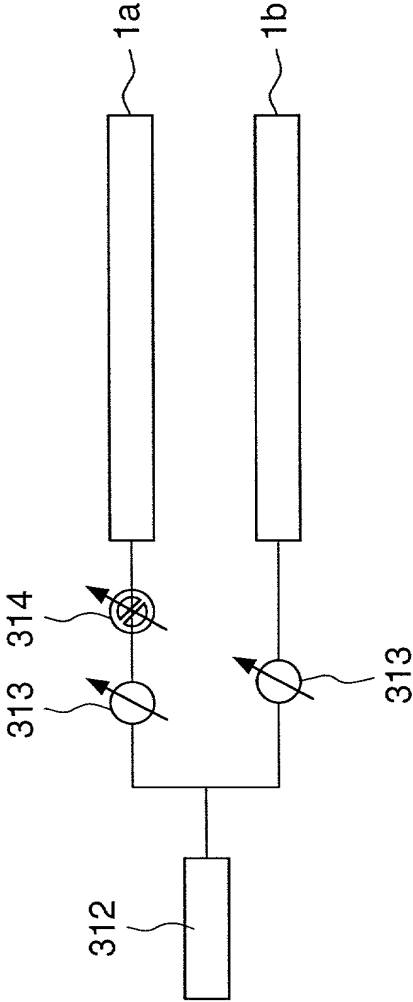


FIG. 48



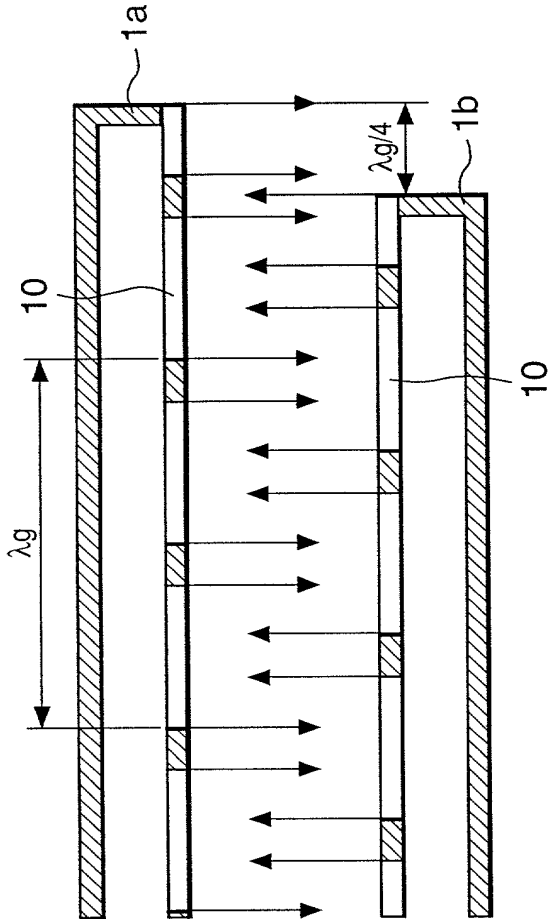


FIG. 49A

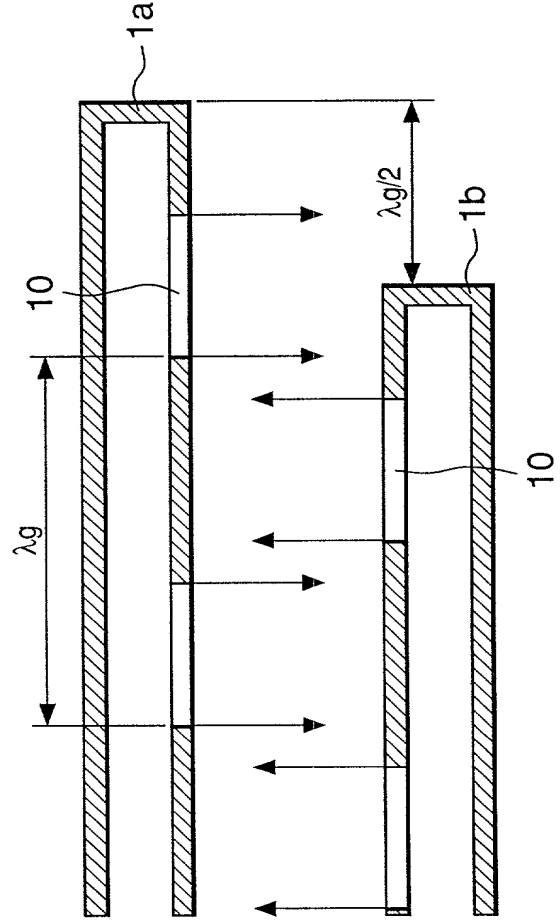


FIG. 49B

FIG. 50

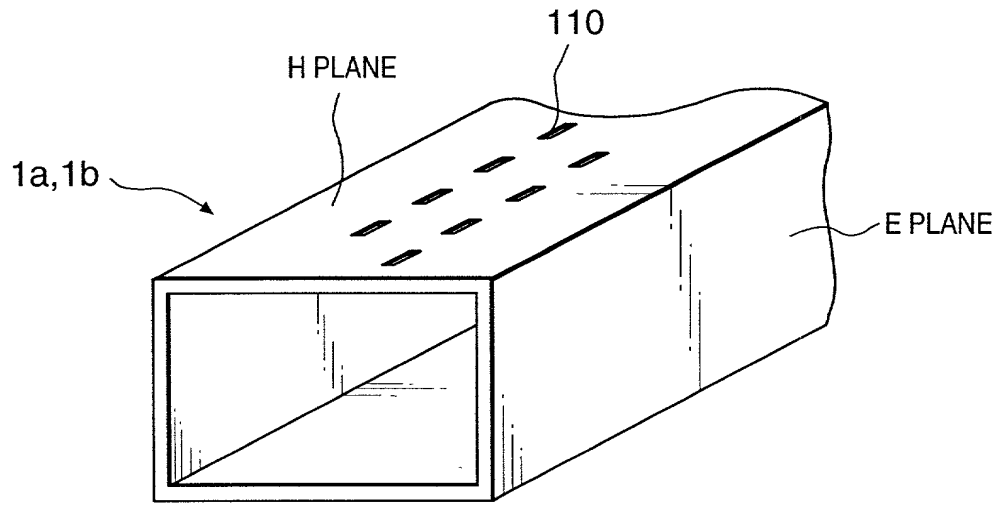
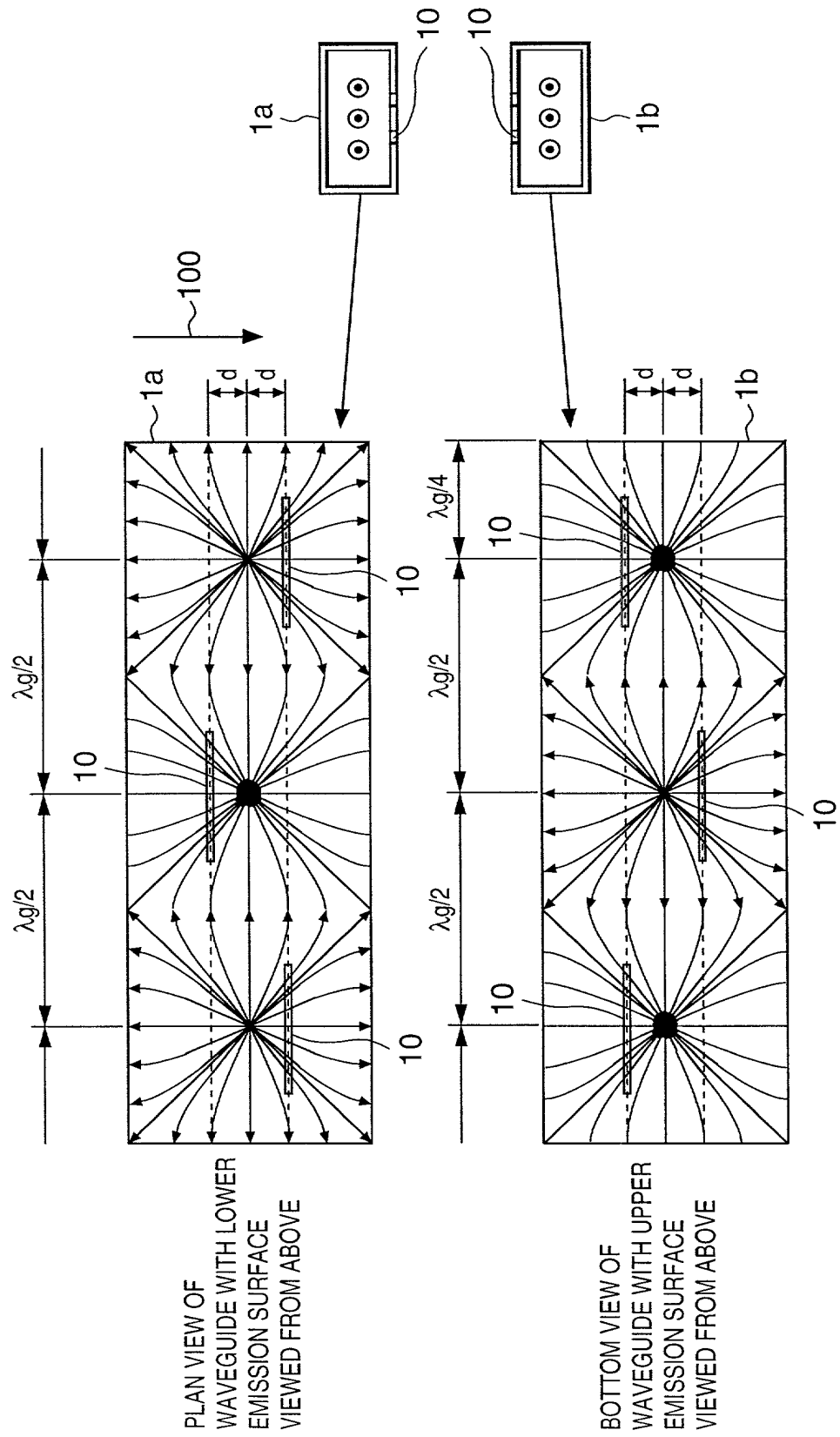


FIG. 51



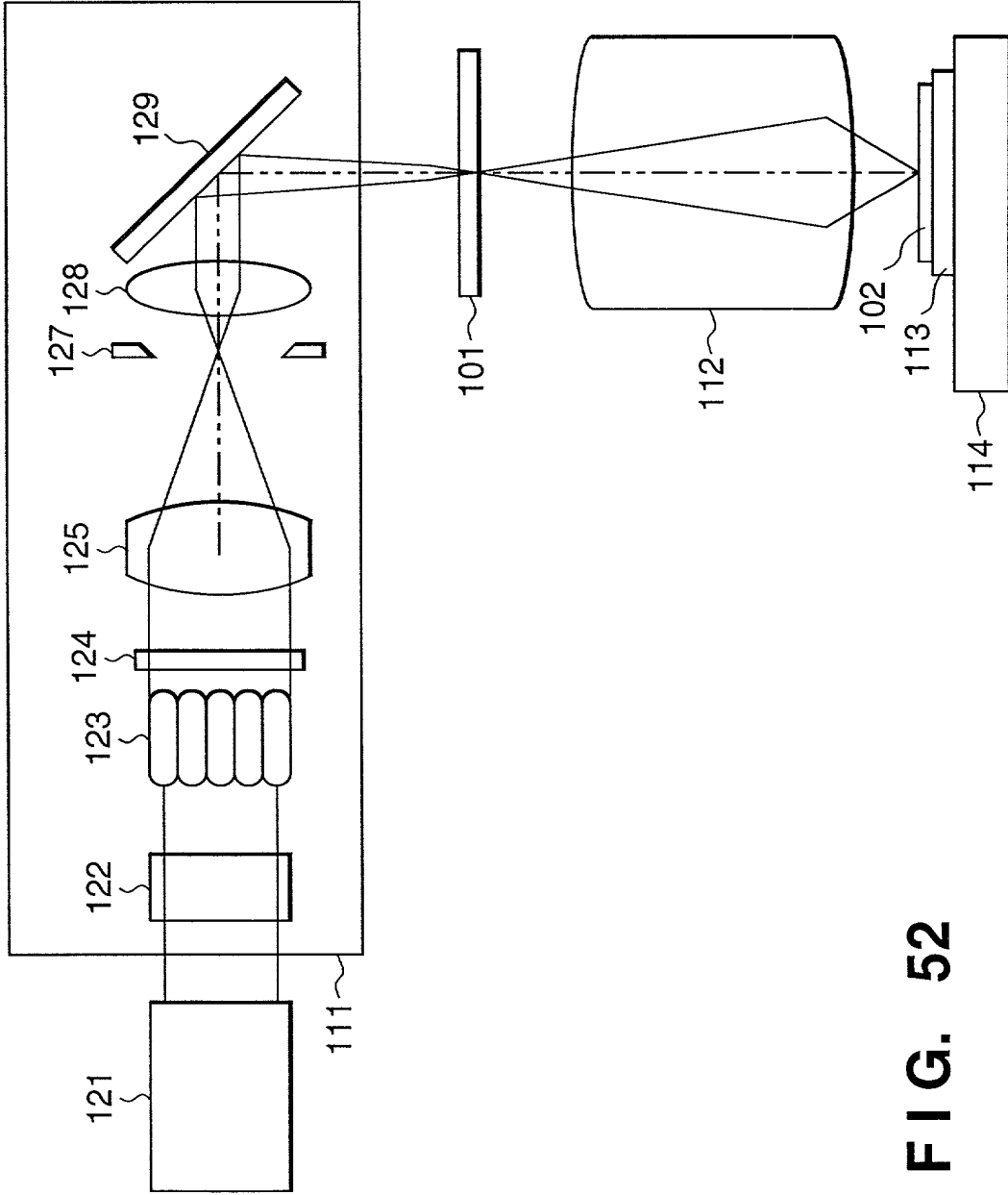


FIG. 52

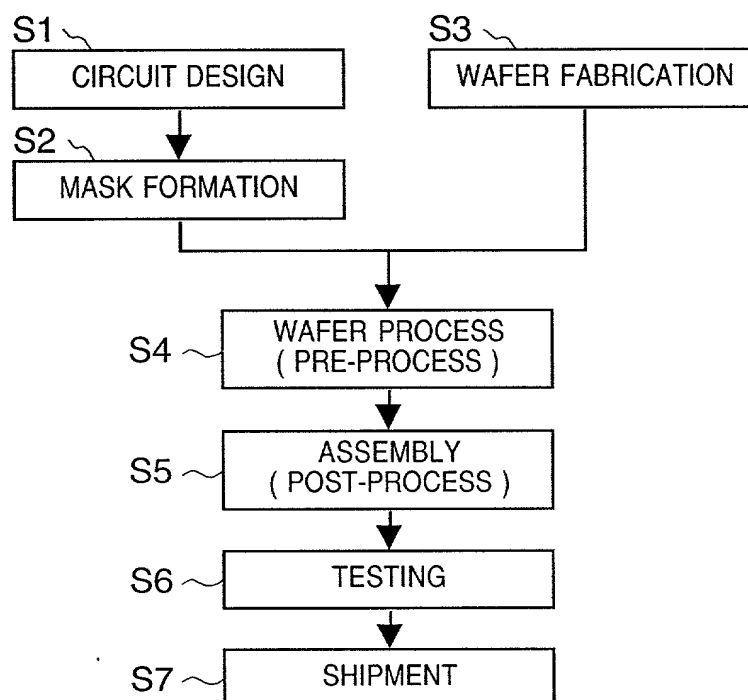
[illegible]

FIG. 54

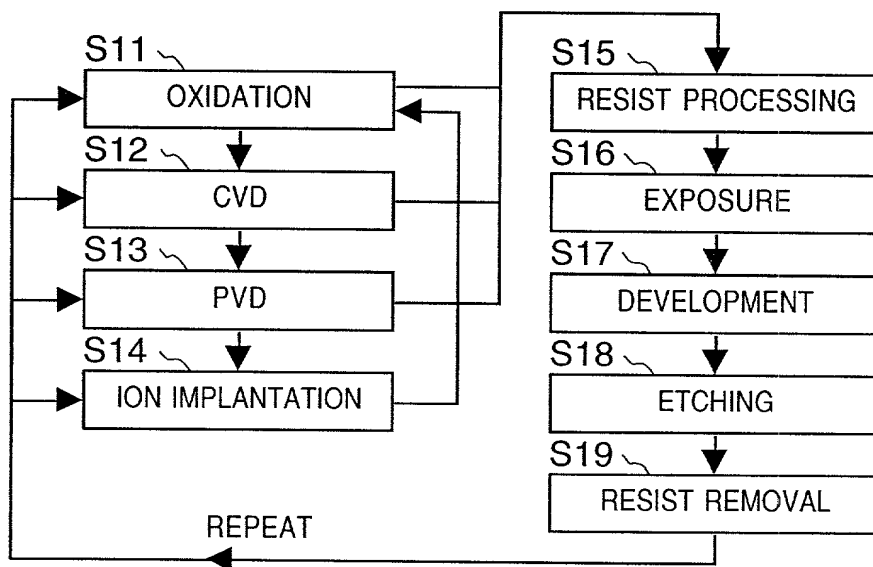


FIG. 55

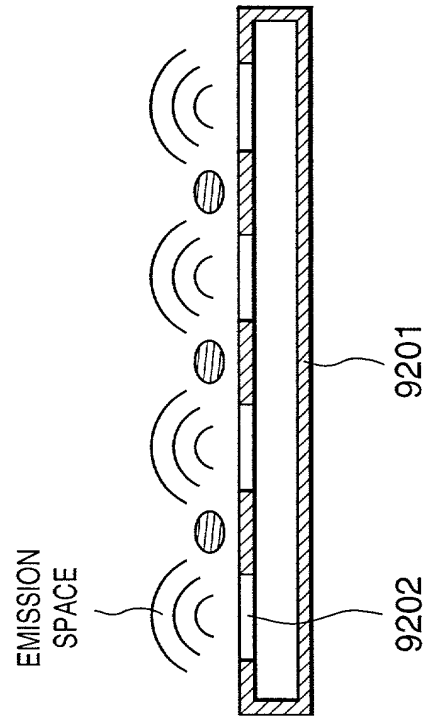


FIG. 56A

EXAMPLE OF ELECTRIC FIELD
INTENSITY NEAR SLOT

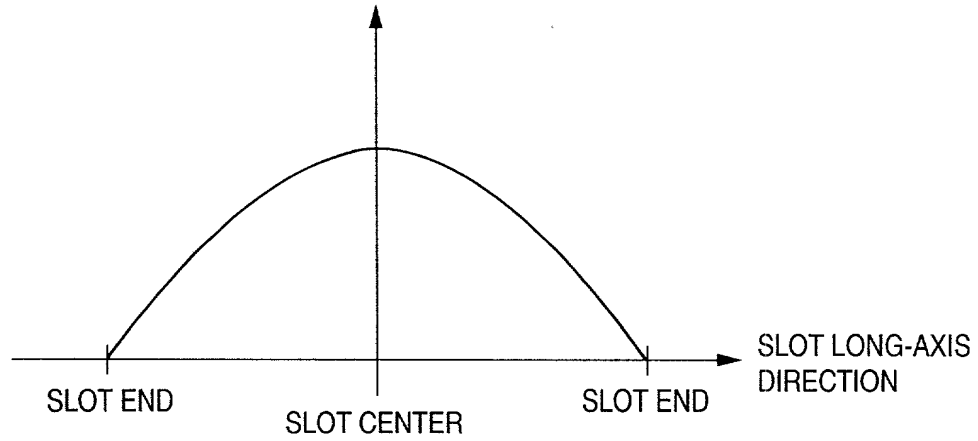


FIG. 56B

PLASMA WAVE INTENSITY
(ALONE)

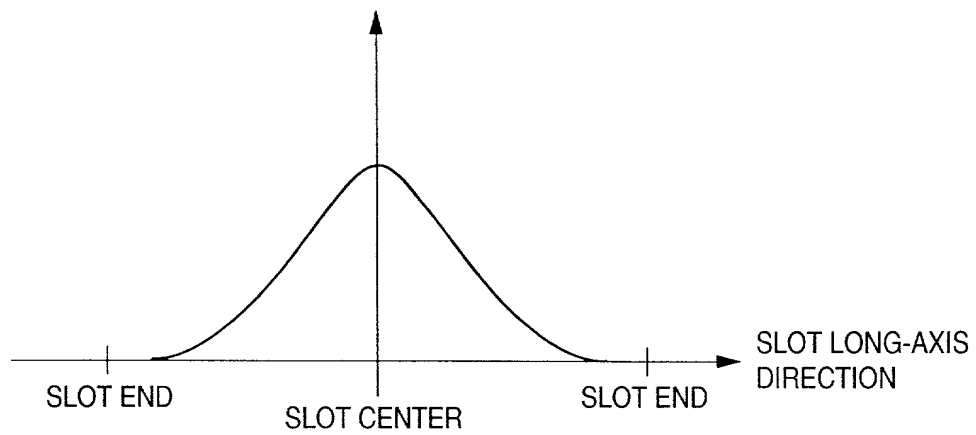
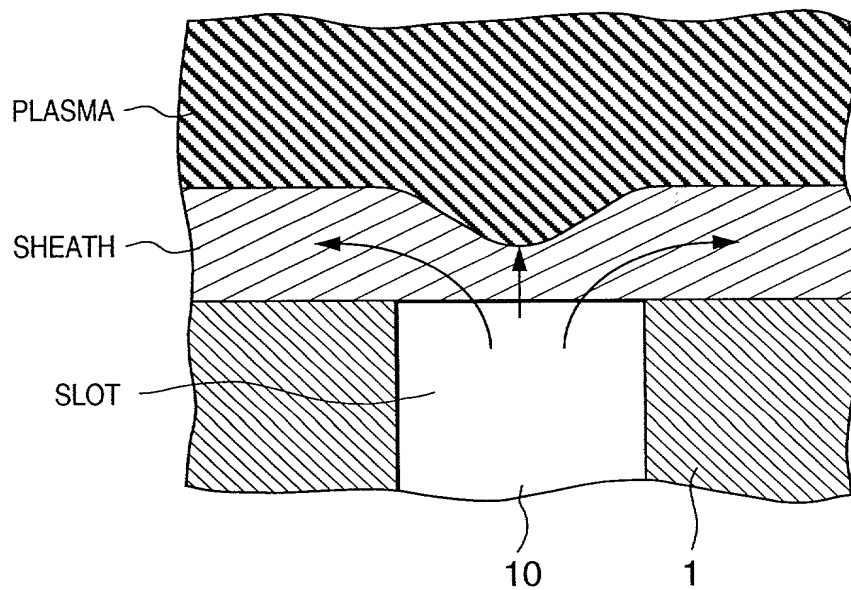


FIG. 57



COMBINED DECLARATION AND POWER OF ATTORNEY
FOR PATENT APPLICATION

(Page 1)

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name;

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled LASER OSCILLATING APPARATUS, EXPOSURE APPARATUS USING THE SAME, AND DEVICE FABRICATION METHOD

the specification of which ☒ is attached hereto ☐ was filed on _____ as United States Application No. or PCT International Application No. _____ and was amended on _____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR §1.56.

I hereby claim foreign priority benefits under 35 U.S.C. §119(a)-(d) or §365(b), of any foreign application(s) for patent or inventor's certificate, or § 365(a) of any PCT international application which designates at least one country other than the United States, listed below and have also identified below any foreign application for patent or inventor's certificate, or PCT international application having a filing date before that of the application on which priority is claimed:

<u>Country</u>	<u>Application No.</u>	<u>Filed (Day/Mo./Yr.)</u>	<u>(Yes/No)</u> <u>Priority Claimed</u>
Japan	11-023902	February 1, 1999	Yes
Japan	11-051807	February 26, 1999	Yes
Japan	11-051808	February 26, 1999	Yes
Japan	11-051809	February 26, 1999	Yes
Japan	11-051810	February 26, 1999	Yes
Japan	11-051812	February 26, 1999	Yes
Japan	11-051813	February 26, 1999	Yes

I hereby claim the benefit under 35 U.S.C. § 119(e) of any United States provisional application(s) listed below:

<u>Application No.</u>	<u>Filed (Day/Mo./Yr.)</u>
------------------------	----------------------------

I hereby claim the benefit under 35 U.S.C. § 120 of any United States application(s), or § 365(c) of any PCT international application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT international application in the manner provided by the first paragraph of 35 U.S.C. § 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 C.F.R. § 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

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[illegible]

I hereby appoint the practitioners associated with the firm and Customer Number provided below to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith, and direct that all correspondence be addressed to the address associated with that Customer Number:

FITZPATRICK, CELLA, HARPER & SCINTO
Customer Number: 05514

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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COMBINED DECLARATION AND POWER OF ATTORNEY
FOR PATENT APPLICATION
(Page 3)

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TCG/fdb/ltp